ICAR Network Project

on

Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change

**Annual Progress Report
(2007-2008)**

<u>Coordinating center</u>
Indian Agricultural Research Institute, New Delhi

<u>Collaborating centers</u>

- Central Plantation Crops Research Institute, Kasaragod

- Central Research Institute for Dryland Agriculture, Hyderabad

- Indian Institute of Horticultural Research, Bangaluru

- CSK Himachal Pradesh Agricultural University, Palampur

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

- ICAR Research Complex for Eastern Region, Patna

- National Dairy Research Institute, Karnal

- Central Marine Fisheries Research Institute, Cochin

- Central Inland Fisheries Research Institute, Barrackpore

- Tamil Nadu Agricultural University, Coimbatore

INDEX

ANNEXURE 3: Budget allocation and expenditure of different Institutes

ANNEXURE 4: Specific Objectives of the individual centres

ANNEXURE 5: Executive Summary by different centres

ANNEXURE 6: Detailed Progress Report   28

ANNEXURE 7: Papers Published

Coordinating Institute: Indian Agricultural Research Institute, New Delhi 110 012

Department /Division: 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 11th plan

Total Cost of the scheme Rs. (in lakhs): 147.554

Budget allocation for this year and expenditure: Annexure 3

Objectives

o   To quantify the sensitivities of current food production systems to different scenarios of climatic change by integrating the response of different sectors
o   To quantify the least-risk or 'no regrets' options in view of uncertainty of global environmental change which would also be useful in sustainable agricultural development
o   To determine the available management and genetic adaptation strategies for climatic change and climatic variability
o   To determine the mitigation options for reducing global climatic changes in agro-ecosystems
o   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 centre-wise summaries

   1. Analysis of emissions of carbon dioxide and nitrous oxide from soil in elevated temperature indicated that the cumulative flux of $N_2O\text{-}N$ from fertilized soil increased by 21% over the ambient soil conditions in kharif season while in rabi, the cumulative flux of carbon dioxide was found to be 12% higher in elevated temperature conditions than in the ambient.

2. In Andhra Pradesh, the percentage of occurrence of droughts were more during 1971-1980 and 1991-2000 decades when compared to 1981-1990 decade in all agro-climatic zones except Southern and Scarce rainfall zones

3. Simulation studies using InfoCrop indicated that in Himachal Pradesh, temperature rise by 1^oC and 2^0C and reduction in rainfall cause decrease in maize yield by 2 to 10 %. In Bihar, maize yields are likely to go up by 13 to 38%, while a reduction in wheat and rice yield up to 25% and 37%, respectively could be expected with the climate change scenarios in 2020, 2050 and 2080.

4. In Tamil Nadu, rice production during southwest monsoon is expected to be affected more compared to northeast monsoon due to climate change. The reduction up to 35 and 50 per cent could be noticed in 2050 and 2080, respectively, in southern region of Tamil Nadu. During northeast monsoon, crop yields are likely to increase by 5 to 15 per cent in most of the locations due to climate change. Maize and sorghum yields are likely to reduce by 2.9 to 26.4% during 2020, 2050 and 2080 from the current yield levels if adaptation strategies are not implemented.

5. Using the coconut model, climate change impacts on coconut yield are simulated for HadCM3 A2a, B2a and A1F 2020, 2050 and 2080 scenarios. Results indicate positive effect on coconut yields in west coast and parts of TN and Karnataka and negative effects on nut yield in east coast of India. However, in the event of reduced availability of irrigation, the beneficial impacts will be less or negative impacts will be more.

6. Experiments conducted in Temperature Gradient Tunnels indicated that biomass and yield of soybean, greengram and potato reduced with rise in temperature (1- 4 ^oC) owing to reduction in yield attributes. Compared to vegetative growth, reproductive growth showed greater sensitivity to high temperature stress in almost all the crops.

8. In chickpea, exposure to high temperature for a fortnight at flowering stage reduced the sterility of pods, which had a beneficial effect on growth, and yield. Among the crops, wheat showed higher degree of sensitivity to high temperature as compared to legumes (greengram, soybean) and oilseeds (mustard, groundnut).

9. Elevated CO_2 increased the productivity of greengram, soybean, chickpea and potato owing to increase in biomass and seed/tuber no. and their size. Groundnut crop showed positive response to elevated CO_2 levels for growth and yield and the response was significantly evident at 700ppm. In groundnut moisture stress at initial stages improved the total biomass and pod yield in all the treatments and the response was more at higher levels of CO_2. Tomato and onion crops showed a yield increase of 25% at elevated CO2 concentration of 550ppm.

11. The total consumption of castor foliage by *Spodoptera litura* during the entire feeding period was significantly more under elevated CO_2 conditions than ambient and chamber controls indicating 39% more consumption under elevated CO_2 conditions.

12. Stressful THI with 20h or more daily THI-hrs (THI >84) for several weeks affect animal responses. The animal thermal load is not dissipated that cause economic losses. Under climate change scenario increased number of stressful days with a change in Tmax and Tmin and decline in availability of water will further impact animal productivity and health in Punjab, Rajasthan and Tamil Nadu. The change in seasonal mean temperatures and in the extreme temperatures in the future will impact animal reproductive cycles, milk yield and production The night temperature increase will not permit animals to dissipate their thermal loads and recovery to normal will be affected.

13. Analysis of historical data showed that the Indian mackerel is able to adapt to rise in sea surface temperature by extending distribution towards northern latitudes, and by descending to depths. The mackerel was conventionally caught by surface drift gillnets by artisanal fishermen. In recent years, however, the fish is increasingly getting caught in bottom trawl nets operated by large mechanized boats at about 50 m depth. In 1985, only 2% of the total mackerel catch was from bottom trawlers. In the last five years, about 10% of the mackerel catch is by the bottom trawlers. This shows that as the sea surface temperature became warmer, the fish descended down.

14. To estimate the carbon foot print by marine fishing boats by data were collected on the diesel consumption from about 1332 mechanized boats and 631 motorized boats in the major fishing harbors along the east and west coast of India. Initial estimates indicate that fossil fuel consumption by marine fishing boats is around 1200 million liters per year and CO2 emission by marine fishing sector is around 2.4 million tonnes per year.

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

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

Details of Progress Report: Annexure 6

Pares Published Annexure 7

Signature of the Principal Investigator

Name: P.K. Aggarwal
Designation: Network Coordinator & National Professor

ANNEXURE 1: Co-Investigators:

Indian Agricultural Research Institute, NEW DELHI

- **Name   : Dr. S.D. Singh, Principal Investigator**
  Designation   : Principal Scientist, Division of Environmental Sciences

- Name   : Dr. Santha Nagarajan,
  Designation   : Principal Scientist, Nuclear Research Laboratory

- Name   : Dr. R. Choudhary
  Designation   : Principal Scientist, Division of Environmental Sciences

- Name   : Dr. Madan Pal
  Designation   : Senior Scientist, Division of Plant Physiology

- Name   : Dr. Subash Chandra
  Designation   : Senior Scientist, Entomology

- Name   : Dr. Anjali Anand
  Designation   : Senior Scientist, Nuclear Research Laboratory

- Name   : Dr. Arti Bhatia
  Designation   : Senior Scientist, Division of Environmental Sciences

- Name   : Dr. Niveta Jain
  Designation   : Senior Scientist, Division of Environmental Sciences

- Name   : Dr. Bidisha Benerjee
  Designation   : Scientist, Division of Environmental Sciences

Central 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

Central Research Institute for Dryland Agriculture, HYDERABAD

- **Name   : Dr. GGSN Rao, Principal Investigator**
  Designation   : Project Coordinator

- Name   : Dr. M. Vanaja
  Designation   : Senior Scientist, Plant Physiology

- Name   : Dr. M. Srinivasa Rao
  Designation   : Senior Scientist, Agricultural Entomology

- Name   : Dr. Y.S. Ramakrishna
  Designation   : Director

- Name   : Mr. A.V.M. Subba Rao
  Designation   : Scientist, (Agromet)

- Name   : Dr. M. Maheswari
  Designation   : Senior Scientist, Plant Physiology

- Name   : Dr. N. Jyothi Laxmi
  Designation   : Senior Scientist, Plant Physiology

Indian Institute of Horticultural Research Institute, BANGALORE

- **Name   : Dr.N.K. Srinivasa Rao, Principal Investigator**
  Designation   : Principal Scientist

- Name   : Dr. R.M. Bhatt
  Designation   : Principal Scientist

- Name   : Dr. R.H. Laxman
  Designation   : Senior Scientist

- Name   : Dr. K.S. Shivashankar
  Designation   : Senior Scientist

CSK Himachal Pradesh Agricultural University, PALAMPUR

- **Name** : **Dr.Ranbir Singh Rana, Principal Investigator**
  Designation : **Scientist**

- Name : Mr. Vaibhav Kalia
  Designation : Assistant Professor

- Name : Mr. Sanjay Sharma
  Designation :

Central Soil and water Conservation Research and training Institute, DEHRADUN

- **Name** : **Dr. K.P. Tripati, Principal Investigator**
  Designation : **Principal Scientist, (Soil & WCE)**

- Name : Dr. D.R.Sena
  Designation : Scientist Sr.Sclale, (S &WCE) at Vasad, Gujarat

- Name : Dr. H.B. Singh
  Designation : Principal Scientist ,(Agronomy) at Vasad, Gujarat
- Name : Dr. S.P.Tiwari
  Designation : Senior Scientist ,(Agronomy) at Vasad, Gujarat

- Name : Er. Sridhara Patra
  Designation : Scientist ,(S& WCE) at Deharadun

ICAR Research Complex for Eastern Region, PATNA

- **Name** : **Dr. Alok K. Sikka, Principal Investigator**

- **Designation** : Director (upto Ist November 2007)

  Dr. Abdul Haris A. (From 2nd November 2007)

- Name : Dr. A. Abdul Haris
  Designation : Senior Scientist

- Name : Dr. Abdul Islam
  Designation : Senior Scientist

- Name : Dr. R. Elanchezhian
  Designation : Senior Scientist

National Dairy Research Institute, KARNAL

- **Name   : Dr. R. C. Upadhyay**, **Principal Investigator**

  Designation   : Principal Scientist (Animal Physiology)

- Name   : Dr. Smitha Sirohi
  Designation   : Senior Scientist, (Economics), DES&M Division

- Name   : Dr. Sohan Vir Singh
  Designation   : Senior Scientist, (Animal Physiology), DCP Division

- Name   : Dr. Ashutosh
  Designation   : Scientist SS, (Animal Physiology), DCP Division

Central Marine Fisheries Research Institute, COCHIN

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

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

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

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

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

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

- Name   : Dr. P.K. Krishna Kumar, Principal scientist
  Designation   : Veraval R.C. of Division, Veraval

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

Central Inland Fisheries Research Institute, BARRACKPORE

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

- Name   : Dr. Mrinal Mukhopadhyaya
  Designation   : Principal Scientist

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

Tamilnadu Agricultural University, COIMBATORE

- **Name**   **: Dr. Palanisamy, Principal Investigator**
  Designation   **: Director, Water Technology Center**

- Name   : Dr. C.R. Ranganadhan
  Designation   : Professor, Maths

- Name   : Dr. Geethalakshmi
  Designation   : Professor

ANNEXURE 2: Research Associates and Senior Research Fellows

Indian Agricultural Research Institute, New Delhi (Coordinating center)

Name	From (date)	Till (date)
Mrs. D.N.Swarupa Rani	09.05.2005	31.03.2008
Ms. Anima Biswal	18.10.2007	13.03.2008
Mrs. Rani Saxena	03.05.2005	07.12.2007
Dr. Yashwant Das	12.10.2007	31.03.2008

Indian Agricultural Research Institute, New Delhi

Name	From (date)	Till (date)
Ms. Surabhi Jain (RA)	09.05.2005	31.03.2008
Dr. Lal Bahadur (RA)	18.10.2007	13.03.2008
Mr. Ram Nivas Yadav (SRF)	03.05.2005	07.12.2007
Ms. Shilpi Mishra (SRF)	12.10.2007	31.03.2008
Ms. S. Kalpana (SRF)	08.10.2007	31.03.2008
Dr. Vinay Kumar Singh (SRF)	15.11.2007	31.03.2008
Mr. Nand Kishore (SRF)	18.10.2007	31.03.2008

Central Plantation Crops Research Institute, Kasaragod

Name	From (date)	Till (date)
John Sunoj, V.S. (SRF)	6.7.2007	To date
Murali Krishna, K.S. (SRF)	9.7.2007	To date
Vineetha, V.P. (SRF)	11.7.2007	To date

Central Research Institute for Dryland Agriculture, Hyderabad

Name	RA/ SRF	From	To
Mr. Santhi Bhushan	RA	01.04.2007	29.02.2008
Mr. N. Mani Kandan	SRF	01.07.2007	31.03.2008
Dr. P. Ratna Kumar	SRF	01.01.2007	31.12.2007
Mrs. P. Vagheera	SRF	04.06.2007	31.03.2008
Mr. SK. Abdul Razak	SRF	18.01.2008	31.03.2008
Ms. V. Pallavi	SRF	21.05.2007	31.03.2008
Mrs. G. Sree Vani	SRF	01.08.2007	31.03.2008

Indian Institute of Horticultural Research, Bangaluru

Name	From (date)	Till (date)
Miss G.M. Ashwini	15.12.2005	Continuing
Miss.V.H.Prabhavathy	04.08.2006	Continuing
Dr. Surendra M.Potalkar	01.10.2007	29.01.2008
Miss. GA Geetha	18.02.2008	Continuing

CSK Himachal Pradesh Agricultural University, Palampur

Name	From (date)	Till (date)
Dr. Anil Mahajan RA	1.9. 2007	30.11.2007
Dr. Sandeep Menon RA	8.2. 2008	31.3.2008
Ms. Kushmita Nag SRF	21.8.2006	30.11.2007
Dr. Deepika Sood SRF	29.8.2007	31.3.2008
Sh. Vivek Rana, Investigator	17.1.2007	31.3.2007

Central Soil and Water Conservation Research and Training Institute, Dehradun

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

ICAR Research Complex for Eastern Region, Patna

Name	From (date)	Till (date)
Ms. Vandana Chhabra	12.07.2005	Continuing
Ms. Anamika	09.12.2005	Continuing
Mr. Arvind Pratap	10.09.2007	Continuing
Mr. Sandeep Biswas	11.09.2007	Continuing
Mr. Hemant Kumar	10.08.2007	28.02.08
Mr. Sudarshan Prasad	03.06.2005	February 2007

National Dairy Research Institute, Karnal

Name	From (date)	Till (date)
Ms Nitika Rani	21/1/2008	Continuing
Mr. Sandeep K.Gupta, SRF	4/2/2006	20/9/2007
Mr Sarvesh Kumar, SRF	5/10/2007	31/12/ 2007
Mr. Vijay Krishna, SRF	3/1/2008	31/3/2008
Mr. Sandeep K. Gupta, RA	21/9/2007	29/2/2008.

Central Marine Fisheries Research Institute, Cochin

Name	From (date)	Till (date)
Jasper B	25.06.2007	31.03.2008
Gopika.N	25.06.2007	19.03.2008
Manjusha.U	25.06.2007	31.03.2008
Remya.R	23.07.2007	31.03.2008
Ratheesan.K	24.07.2007	31.03.2008
Poonam Ashok Khandagale	26.09.2007	31.03.2008

Central Inland Fisheries Research Institute, Barrackpore

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

Tamil Nadu Agricultural University, Coimbatore

Name	From (date)	Till (date)
S.Senthilnathan, SRF (Working as a RA from 11.09.08)	11.06.2007	Working till date
S.Govindaraj, SRF	20.06.2007	Working till date
N.Geethadevi, SRF	13.02.2008	Working till date
Nagaraj	21.06.2007	Resigned on - 31.03.08
Poornima	23.11.2007	Resigned on - 31.03.08
P.Priya	01.10.2007	Resigned on - 21.03.08
Bhuvaneshwari	18.06.07	Resigned on - 14.12.07
Rao	12.10.2007	Resigned on - 29.01.08

ANNEXURE 3: Budget allocation* and expenditure of different Institutes (Provisional)

(*These figures need to be confirmed by CRIDA, Hyderabad)

Indian Agricultural Research Institute, New Delhi

Budget allocation and expenditure:

TA	OTA	RC	Contractual service	Workshop	POL	Total RC (1+2+3+4+5+6)	NRC	Intuitional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
1.00	0.050	5.00	12.840	0.50	0.100	19.49	6.00	2.64	28.13

Total amount spent in 2007-08

TA	OTA	RC	Contractual services	Workshop	POL	Total RC (1+2+3+4+5+6	NRC	Intuitional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
105279		65828	498752	0	0		0	58515	728374

Central Plantation Crops Research Institute, Kasaragod

Budget allocation for 2007-08

TA	OTA	RC	Contractual services	Work shop	POL	TotalRC (1+2+3+4+5+6	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	0.05	3.00	4.500	0.00	0.20	8.50	4.50	1.30	14.30

Total amount spent in 2007-08

TA	OTA	RC	Contractual services	Work shop	POL	Total RC (1+2+3+4+5+6	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
42,573	0	1,96,801	2,09,911	0	14,562	4,63,847	0	85,037	5,48,884

Central Research Institute for Dryland Agriculture, Hyderabad

Budget allocation for 2007-08

TA	OTA	Recurring Contingencies	Contractual services	Work shop	POL	Total RC (1+2+3+4+5+6	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	0.1	5.0	9.42	1.0	0.2	16.47	6.0	2.247	24.717

Total amount spent in 2007-08

TA	OTA	Recurring Contingencies	Contractual services	Work shop	POL	Total RC (1+2+3+4+5+6	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
1.07	0	4.69	6.37	0	0	12.13	0	1.29	13.42

*Provision has been withdrawn and expenditure shall be adjusted either with the overall saving in the other head.

Indian Institute of Horticultural Research, Bangaluru

Budget allocation for 2007-08

TA	OTA	Recurring Contingencies	Contractual services	Work shop	POL	Total RC (1+2+3+4+5+6	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	0.050	4.0	4.5	0.00	0.2	9.5	4.00	1.35	14.85

Total amount spent in 2007-08

TA	OTA	Recurring Contingencies	Contractual services	Work shop	POL	Total RC (1+2+3+4+5+6	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
1.246	0	4.82	2.32	0	0.2	8.58	0	0	8.58

CSK Himachal Pradesh Agricultural University, Palampur

Budget allocation and expenditure:

TA	OTA	RC	Contractual service	Workshop	POL	Total RC (1+2+3+4+5+6)	NRC	Institonal charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	0.05	2.0	4.92	0	0.2	7.92	2.0	1.0	10.92

Total amount spent in 2007-08

TA	OTA	RC	Contractual service	Workshop	POL	Total RC (1+2+3+4+5+6)	NRC	Institonal charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
22522	0	199593	202249	0	20000	444364	0	79200	523564

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

Central Soil and Water Conservation Research and Training Institute, Dehradun

Budget allocation for 2007-08

TA	OTA	Recurring Contingencies	Contractual services	Work shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institutional Charges	Total
0.750	0.050	2.000	4.500	0.000	0.200	7.50	3.0	1.05	11.550

Total Amount Spent in 2007-08

TA	OTA	Recurring Contingencies	Contractual services	Work shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institutional Charges	Total
33278	0.0	1.67856	0.00	0.00	0.0	2.01134	0.00	0.00	2.01134

ICAR Research Complex for Eastern Region, Patna

Budget allocation for 2007-08

TA	OTA	RC	Contractual service	Workshop	POL	Total RC (1+2+3+4+5+6)	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	0.05	3.0	7.92	0	0.2	11.92	5	1.692	18.612

Total Amount Spent in 2007-08

TA	OTA	RC	Contractual service	Workshop	POL	Total RC (1+2+3+4+5+6)	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.67789	0.0	2.48841	4.03473	0.0	0.0	7.20103	0	1.692	8.89303

Note: Amount spent is less because all the contractual staff was not in position and also the arrear pay for them was not paid as the order was received only on 28th march and equipments under NRC could not be used for want of sanction from ICAR

National Dairy Research Institute, Karnal

Budget allocation for 2007-08

TA	OTA	RC	Contractual service	Workshop	POL	Total RC (1+2+3+4+5+6)	NRC	Institonal charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
75,000	5000	3,00,000	6,42 ,000	0	20,000	1042000	4,00,000	144200	1586200

Total Amount Spent in 2007-08

TA	OTA	RC	Contractual service	Workshop	POL	Total RC (1+2+3+4+5+6)	NRC	Institonal charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
16359	5000	275325	277085	0	0	573769*	38404	0	612173

*Expenditure incurred on accessories of CO2 and O2 Analyser

Central Marine Fisheries Research Institute, Cochin

Budget allocation for 2007-08

TA	OTA	RC	Contractual service	Workshop	POL	Total RC (1+2+3+4+5+6)	NRC	Institutional charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	0.05	4.0	9.0	0	0.20	14.0	6.0	2.0	22.0

Total Amount Spent in 2007-08:(Statement of Expenditure enclosed)

TA	OTA	RC	Contractual service	Workshop	POL	Total RC (1+2+3+4+5+6)	NRC	Institonal charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
75325	5000	548033	431655	0	2552	1062565	0	0	1060565

Central Inland Fisheries Research Institute, Barrackpore

Budget allocation and expenditure:

(Amount in rupees)

TA	OTA	RC	Contractual service	Work shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institonal charges	Total (7+8+9)
1	2	3	4	5	6		8	9	10
75,000	5,000	3,00,000	4,50,000	0.00	20,000	850000	4,00,000	1,25,000	13,75,000

Total amount spent in 2007-08

(Amount in rupees)

TA	OTA	RC	Contractual services	Work shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institonal charges	Total (7+8+9)
1	2	3	4	5	6		8	9	10
35,554	5,000	2,02,852	3,66,063	0.00	0.00	609469	0.00	1,25,000	7,34,469

Tamil Nadu Agricultural University, Coimbatore

Budget allocation (In Lakhs) for this year (ending by March, 2008):

TA	OTA	RC	Contractual service	Work shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institonal charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
0.75	0.05	4.0	9.0	0.5	0.20	14.50	5.50	2.0	22.00

Total Amount Spent (Rs.): (April, 07 to March, 08):

TA	OTA	RC	Contractual services	Work shop	POL	Total RC (1+2+3+4+5+6)	NRC	Institonal charges	Total (7+8+9)
1	2	3	4	5	6	7	8	9	10
65059	-	342885	398357	23115	-	829416	61100	200000	1090516

ANNEXURE 4: Specific objectives of the individual centers

Indian Agricultural Research Institute, New Delhi

- To assess the impact of elevated CO_2 and temperature on growth, productivity and physiological processes of wheat, chickpea, green gram, soybean, groundnut and mustard using FACE and TGT facilities.
- To assess the growth, yield and quality response of selected crops to elevated day vs night temperature
- To assess the effect of elevated CO_2 level and temperature on quality characters of economic yield of selected crop species.
- To assess the impact of high temperature and CO2 on soil carbon/nitrogen dynamics and emission of greenhouse gases and their mitigation
- To quantify the impact of high temperature and CO2 on pest dynamics in selected crops

Central Plantation Crops Research Institute, Kasaragod

- To validate the coconut model in different agro-climatic regions
- Study the impact of different scenarios of climate change on coconut in different agro-climatic zones using simulation model
- Study the suitability of measures of adaptation in coconut plantations to climate change in different agro-climatic zones using simulation model
- Study the effect of elevated temperature and CO_2 on growth of coconut seedlings.
- Study the carbon sequestration potential and stocks of coconut mono-systems using simulation model.

Central Research Institute for Dryland Agriculture, Hyderabad

- To provide a first estimate of impact of climate change on important commodities based on literature review and expert judgment
- To calibrate and validate Info-Crop model for key food crops in different agro-climatic regions of the state
- To simulate the impacts of different scenarios of climate change on crop production
- To quantify the suitability of various agronomic measures for adaptation to climate change
- Impact of elevated CO_2 and temperature on insect-plant interactions
- To study the growth and yield of groundnut under elevated CO_2 and moisture stress
- To study the impact of enhanced CO_2 levels on seed quality

Indian Institute of Horticultural Research, Bangaluru

- To study the effects of elevated CO_2, temperature, water stress on growth, water use efficiency, quality and yield of tomato and onion.
- To correlate prevailing climatic conditions to phenology, crop performance and quality of grape fruits and wine from different grape growing regions.
- To assess the impact of climate change on onion and tomato using validated InfoCrop model and working out adaptation strategies and assessing vulnerability of these crops under different agro-climatic regions.
- Linking different climate change scenarios with the models to quantify the impact in different agro-climatic regions and GIS mapping of spatial distribution of impacts.

CSK Himachal Pradesh Agricultural University, Palampur

- To provide a first estimate of impact of climate change on important commodities based on literature review and expert judgment.
- To calibrate and validate INFOCROP for key food crops (Maize, wheat and rice) in different agro-climatic region of the state.
- To simulate the impacts of different scenarios of climate change on crop production.
- To quantify the suitability of various agronomic measures for adaptation to climate change

Central Soil and Water Conservation Research and Training Institute, Dehradun

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

ICAR Research Complex for Eastern Region, Patna

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

National Dairy Research Institute, Karnal

- To provide a first estimate of impact of sudden weather changes on livestock growth and milk production based on literature review and expert judgment
- To identify and calibrate NRC model for suitability in Indian dairy animals incorporating changes in temperature and feed intake
- To quantify magnitude of milk production decline in relation to cumulative THI load during hot period and wind chill effects during   cold months.
- To quantify the suitability of various thermal stress alleviating measures for adaptation to climate changes

Central Marine Fisheries Research Institute, Cochin

- To assess the adaptability and vulnerability of marine organisms to elevated seawater temperature.
- To assess the impact on primary and secondary producers.
- To evaluate socioeconomic conditions of coastal communities in the changed scenarios.
- To evolve adaptation and mitigation measures to sustain Indian marine fisheries.

Central Inland Fisheries Research Institute, Barrackpore

- To survey the fish seed hatcheries in the districts of Puri, Khurda, Balasore, Mayurbhanj in Orissa.
- To study the species richness of rivers Mahanadi and Brahamani in districts of Cuttak, Jajpur and Angul.
- To develop a predictive regression model, based on the data of eight macro ecological parameters related to fisheries of 14 major Indian rivers.
- To study the effect of different range of temperature on the growth of fingerlings of *L. rohita*

Tamil Nadu Agricultural University, Coimbatore

- Construction of Composite Vulnerability Index
- Multi Goal Linear Programming (MGLP) for sustainable food security
- To calibrate and validate InfoCrop / DSSAT models for key food crops in different agroclimatic regions of Tamil Nadu.
- To quantify the impacts of different scenarios of climate change on key crops growth and production.
- To quantify the suitability of various agronomic measures for adaptation to climate change

ANNEXURE 5: Executive Summary by each centre

Indian Agricultural Research Institute, New Delhi

- The structural, operational and functional performances of infrastructure facilities (FACE, OTC and TGT) were found to be satisfactory and minor problems could be rectified through further calibration. Results indicated that elevated temperature (+2-3°C) caused differential extent of reduction in growth and yield of different crops viz., rice, greengram, soybean, groundnut, wheat, and chickpea. Among the crops, wheat showed higher degree of sensitivity to high temperature as compared to legumes (greengram, soybean) and oilseeds (mustard, groundnut).

- Biomass and yield of soybean, greengram and potato reduced markedly with rise in temperature (1- 4°C) owing to reduction in yield attributes. Among the yield components, 1000 grain/seed weight showed less sensitivity to high temperature.

- In experiments on exposure to high temperatures ether during day or night, soybean, greengram, groundnut and potato showed reduction in yield under high daytime temperaure, while except potato other three crops yielded more under elevated night temp. In chickpea, exposure to high temperature for a fortnight at flowering stage reduced the sterility of pods, which had a beneficial effect on growth, and yield of crop.

- Elevated CO_2 registered marked increase in the productivity of greengram, soybean, chickpea and potato owing to increase in biomass and seed/tuber no. and their size.

- Analysis on quality parameters in grains/tubers of crops (rice, green gram, soybean and potato) indicated that increased temperature reduced carbohydrate content, while enhanced the level of protein in the grains and tubers. In general, seedling vigour is affected due to elevated temperature. Elevated CO_2, on the other hand, increased sugar and starch contents and decreased protein content in potato. In soybean and green gram also there was reduction in protein content of grain due to elevated CO_2.

- Analysis on emissions of carbon dioxide and nitrous oxide from soil in elevated temperature indicated that the cumulative flux of carbon dioxide did not significantly increase with an average increase of temperature by 3.6^{o}C over a period of 100 days in the kharif season. The cumulative flux of N_2O-N from fertilized soil over 100 days increased by 21% over the ambient soil conditions. In the rabi season, the cumulative flux of carbon dioxide was found to be 12% higher in elevated temperature conditions than the ambient over a period of 115 days.

  - Generic insect population dynamics models were developed based on the concept of thermal times for different phenological stages. The model was validated for holometabolous, hemimetabolous and viviparous type of insect life cycles.

Central Plantation Crops Research Institute, Kasaragod

- Coconut simulation model is developed and validated to different agro-climatic zones. Simulated coconut potential total dry matter production varied across the agro-climatic zones from around 52 $t.ha^{-1}.year^{-1}$ in central southern plateau and hill zone of Karnataka to 62 $t.ha^{-1}.year^{-1}$ at south of southern plateau and hills zone of Tamil Nadu. Potential yields varied from 25 to 30 $t.ha^{-1}.year^{-1}$ depending on the agro-climatic zone.

- Using the coconut model, climate change impacts on coconut yield are simulated for HadCM3 A2a, B2a and A1F 2020, 2050 and 2080 scenarios. Results indicate positive effect on coconut yields in west coast and parts of TN and Karnataka and negative effects on nut yield in east coast of India. However, in the event of reduced availability of irrigation, the beneficial impacts will be less or negative impacts will be more.

- In Open Top Chamber (OTC) studies on coconut seedlings, morpho-physiological and biochemical analysis indicated initial responses of coconut seedlings to elevated temperature (+3 ^{o}C) and CO_2 (550 and 700 ppm) as compared to chamber control. Seedlings grown in elevated CO_2 have higher root dry matter, specific leaf area, chlorophyll a/b ratio, collar girth, shoot height, and shoot dry matter and leaf area as compared to those grown in chamber control. Seedlings exposed to elevated temperature have high shoot height; root length, collar girth and root dry matter and volume as compared to those in chamber control. Starch and reducing sugars were higher in seedlings grown in elevated CO_2 condition as compared to the chamber control seedlings.

- Initial results indicate that elevated temperature during storage adversely effected oil quality in terms of free fatty acids, acid value and peroxide value.

Central Research Institute for Dryland Agriculture, Hyderabad

- The rainfall data of 174 stations well spread over Andhra Pradesh with a period ranging from 1871 to 2004 years was analysed and the significant trends were identified using the Mann Kendall test of significance. Using these values a rainfall trend map of Andhra Pradesh was generated. The percentage of occurrence of droughts was more during 1971-1980 and 1991-2000 decades when compared to 1981-1990 decade in all agro-climatic zones except Southern and Scarce rainfall zones.

- The total consumption of castor foliage by *Spodoptera litura* during the entire feeding period was significantly more under elevated CO_2 conditions than ambient and chamber controls indicating 39% more consumption under elevated CO_2 conditions.

- Groundnut crop showed positive response to elevated CO_2 levels for growth and yield and the response was significantly evident at 700ppm. Moisture stress at initial stages improved the total biomass and pod yield in all the treatments and the response was

more at higher levels of CO_2. The seed weight increased with moisture stress due to higher number of pods and seeds, however reduced 100 seed weight was observed with moisture stress. Both elevated CO_2 levels increased the oil content and the response was more prominent at higher level.

- The unsaturated fatty acids increased over saturated fatty acids with elevated CO_2 levels. It was also observed that the content of Oleic acid showed increasing trend with elevated CO_2 levels where as the reverse trend was with linolenic acid fraction.

Indian Institute of Horticultural Research, Bangaluru

- The InfoCrop model was further 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.

- Validation of the models was taken up with the inputs from experiments conducted at different agro-ecological regions for different seasons, nitrogen and irrigation levels. The data from experiments conducted at Bangalore, Hyderabad, Hisar, New Delhi, Dharwad and Nasik were used for validating onion model and Bangalore, Karnal, Ludhiana, Bhubaneshwar and Hisar for tomato model.

- The preliminary sensitivity analysis of the validated models was done to quantify the impact of increase in temperature and CO_2 on yield. It was observed that the yield reduction in tomato was only up to 20% when the temperature increased up to 5°C. In onion the yield reduction was up to 40% with increase in temperature of 3°C and 75% reduction with 4°C increase

- The analysis of the impact of climate change in terms of deviations in yield for 2020, 2050 and 2080 from base years for both onion and tomato was done. The model outputs on onion showed that, in Nasik region of Maharashtra, a major onion growing region, yields reductions would be more in Kharif season followed by Late Kharif season. Yield reductions would be lowest in Rabi season in 2020, 2050 and 2080 for the all the scenarios studied.

- Response of onion and tomato to elevated CO_2 (550ppm) was studied in Open Top chambers. Tomato recorded a yield increase of 24.4% and onion recorded an increase of 25.9% at elevated CO2 concentration of 550ppm.

- In wine grape cv. Cabernet Sauvignon the relationship between mean maximum and minimum temperature prevailing during veraison to fruit maturity and berry anthocyanin and total flavonoids content showed a negative relationship. The difference between maximum and minimum temperature during the fruit maturation stage was found to have very high influence on berry anthocyanin content.

CSK Himachal Pradesh Agricultural University, Palampur

- Impact of elevated CO_2 levels of 420 ppm and 470 ppm on maize crop under potential conditions and rainfed recommended condition showed an increase of 3.0% and 5.4% and 4.3 and 8.1% in 10th June sown crop respectively. Temperature rise by $1^{o}C$ and $2^{0}C$ and reduction in rainfall caused decrease in maize yield by 2 to 10 %.

- In wheat, results indicated an increase in yield with elevated levels of CO_2 to the tune of 4.9 to 7.3 % in early sown conditions (15th October).

Central Soil and Water Conservation Research and Training Institute, Dehradun

- The relevant toposheets of the seven study watersheds (Almus, Tehri Garhwal; Belura, Maharashtra; Pogalur,Coimbatore; Jonainala, Orissa; Udhagaman-dalam, TamilNadu; Umiam, Meghalaya; Antisar, Kheda,Gujrat) have been scanned, geo-referenced on UTM projection: datum WGS 84.The watershed boundary has been delineated and the contours and the boundary has digitized. The DEM has also been generated on Arc-view. The data of soil and land use, groundwater level and daily weather has been compiled for use in hydrological and crop models.

ICAR Research Complex for Eastern Region, Patna

- Projection using climate change scenarios indicate a likely increase in maize yields ranging from 13 to 38% while a reduction in wheat and rice yield is likely up to 25% and 37%, respectively with the climate change scenarios in 2020, 2050 and 2080 at Pusa. At Sabour a reduction up to 50% is projected for wheat yields and 15% reduction in rice yields.

- Analysis of past data indicated a decreasing trend in mean monthly streamflow in Upper Bhavani basin (lying upstream of the Bhavanisagar Reservoir with the two main rivers the Bhavani and the Moyar) in almost all the months except May and Jan was observed.

National Dairy Research Institute, Karnal

- Very high and low environmental temperatures and lack of prior conditioning result in to low production of livestock managed in unprotected or open or partially protected buildings. Heat and Cold wave with high wind velocity can push vulnerable animals beyond their survival threshold limits of high and low temperature. The consequences of exposure to extreme cold could be severe particularly in Indian animals not adapted to severe cold with high wind velocity. Covering of animals with loose, lightweight and warm jute materials (gunny bags clothing) can help in protection and excessive heat loss from body. Tightly-woven and water-repellant outer covers can further protect them from wet winters and wind chill effects.
- Stressful THI with 20h or more daily THI-hrs (THI >84) for several weeks affect animal responses. The animal thermal load is not dissipated that cause economic losses. Under climate change scenario increased number of stressful days with a change in Tmax and Tmin and decline in availability of water will further impact

animal productivity and health in Punjab, Rajasthan and Tamil Nadu. The change in seasonal mean temperatures and in the extreme temperatures in the future will impact animal reproductive cycles, milk yield and production The night temperature increase will not permit animals to dissipate their thermal loads and recovery to normal will be affected.

Central Marine Fisheries Research Institute, Cochin

- The Indian mackerel *Rastrelliger kanagurta*, one of the commercially important pelagic fish, is able to adapt to rise in sea surface temperature by extending distribution towards northern latitudes, and by descending to depths. During 1961-76, the mackerel catch along the northwest coast of India contributed about 7.5% to the all India mackerel catch, which increased to 18% during 1997-06. In the northeast coast, the mackerel catch contributed 0.4% to the all India mackerel catch during 1961-76, which increased to 1.7% during 1997-06. The mackerel was conventionally caught by surface drift gillnets by artisanal fishermen. In recent years, however, the fish is increasingly getting caught in bottom trawl nets operated by large mechanized boats at about 50 m depth. In 1985, only 2% of the total mackerel catch was from bottom trawlers. In the last five years, about 10% of the mackerel catch is by the bottom trawlers. This shows that the fish descends down to overcome warmer surface waters.

- To estimate the carbon foot print by marine fishing boats by data were collected on the diesel consumption from about 1332 mechanized boats and 631 motorized boats in the major fishing harbors along the east and west coast of India. Initial estimates indicate that fossil fuel consumption by marine fishing boats is around 1200 million liters per year and CO_2 emission by marine fishing sector is around 2.4 million tonnes per year.

- Many of the coastal fishing villages are vulnerable to sea level rise as they are located close to the seashore. To identify the most vulnerable villages, a survey on the distance from high-tide line (HTL) to each fishing village was undertaken. Demographic details and infrastructure available in the fishing villages of maritime states were collected. There are about 2643 fishing villages along the Indian coast, out of which 458 are within 100m from the high tide line. The largest number of coastal fishing villages, (about 200) within 100m, are in Kerala. The population in the 458 coastal fishing villages is around 1 million. The data on vulnerable fishing villages will be helpful for estimating the cost of relocating the villages; and sensitize the fishing communities on the perils of rising sea level.

Central Inland Fisheries Research Institute, Barrackpore

- Under controlled laboratory conditions, the fingerlings of *L. rohita* were kept in different temperatures and *ad libitum* feeding. They showed conspicuous responses for their food conversation, food consumption, specific growth and weight gain with thermal variations in ambient waters. 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 to 35ºC. With 4ºC increase in temperature from 29ºC to 33ºC the values raised by 12.29 % and when the ambient temperature of the fishes was increased to 34ºC the improvement was to the tune of 38.69%. However, when fishes exposed to 35ºC the weight was declined by 30.10% compared to that at 34ºC.

Tamil Nadu Agricultural University, Coimbatore

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

- Analysis using the multi-linear goal programming model, indicated that possibility of increasing the total rice production by 1.58 million tonnes, which accounts for 31.23 per cent more than the existing current level from the different agro climatic regions of Tamil Nadu even by imposing all the constraints. At State level, even with all constraints are included, the farm income can be increased by about 51 billion rupees which is 108 per cent higher than the existing level of income earned by the farmers.

- Future changes in rainfall, maximum temperature and minimum temperature for 2020, 2040 and 2080 over the baseline data (2000) for Tamil Nadu region indicates that the precipitation may increase by 10 to 15 per cent during southwest monsoon season (June – September) while, there may be a slight reduction in rainfall in the south western zone alone during northeast monsoon season. With respect to temperature, there is an increase of 2.5 to 5°C is expected in both the seasons and more increase is expected in minimum temperature compared to maximum temperature.

- Study on impacts of climate change on rice production indicated that the rice production during southwest monsoon is expected to be affected more compared to northeast monsoon due to climate change. The reduction up to 35 and 50 per cent could be noticed in 2050 and 2080, respectively, in southern region of Tamil Nadu. The central eastern zone is the next vulnerable zone contributing 20 and 35 per cent yield reduction during 2050 and 2080, respectively. It is quite interesting to note that there is an increase in yield of 5 to 15 per cent in most of the locations during 2020 in northeast monsoon. During 2050, there is a slight reduction (10 – 15 %) in yield is expected in the southern zone. During 2080, in almost all the zones reduction would be 20 to 35 per cent.

- Analysis on the maize crop indicated that due to global warming, maize yields will decrease by 2.9, 10.1 and 20.4 per cent respectively during 2020, 2050 and 2080 from the current yield levels. The results of sorghum crop revealed that the expected decline in yields is 4.6, 15 and 24.6 per cent respectively during 2020, 2050 and 2080 from the current yield levels if no management intervention is made.

**ANNEXURE 6**: **Detailed Progress Report**

<center>Indian Agricultural Research Institute, New Delhi</center>

**Objective 1**. To assess the impact of elevated temperature and CO_2 on growth and productivity of different crops

Calibration of Free Air Carbon dioxide Enrichment (FACE) and Temperature Gradient Tunnel (TGT) facility in field

Both FACE and TGT facilities were calibrated and tested in the field. In the FACE system high CO_2 concentration was maintained throughout the crop growth period. The CO_2 concentration was set as 550 ppm and it was recorded by IRGA and automated data logger at regular interval. Temperature, humidity and wind speed inside the rings were also recorded at regular interval. Opening and closing of the solenoid valves in the rings were regulated by the wind speed and direction. Three valves opened at a time in the direction of the wind for CO2 injection. All the valves remained closed when wind speed exceeded a value of 5 m/sec. When CO_2 level in one ring reached the desired level injection started in the second ring. CO_2 concentration varied from 450-550 ppm in kharif and rabi season in both the FACE rings (Fig.1 a & b). Lowest CO_2 value was recorded in the centre which gradually increased towards the periphery of the rings and the gradient was around 30 ppm.

Temperature gradient was formed inside the temperature gradient tunnels (TGT) by blowing air by exhaust fans at both ends of TGT. Sensors installed at five different points in the tunnel measured temperature at 15 minutes interval and was recorded by data logger. Fan speed was adjusted to maintain the temperature gradient. Values of temperature were pooled to obtain weekly temperature data at those points in the tunnels. Then mean temperature values were calculated for both kharif and rabi season. A gradient of 3.5° and 3.2°C was maintained in ring A and B respectively (Fig.2 a) during the kharif season. On the other hand rabi season recorded a gradient of 2.3°C in both the rings (Fig.2 b). Humidity and solar radiation was measured inside both the tunnels.
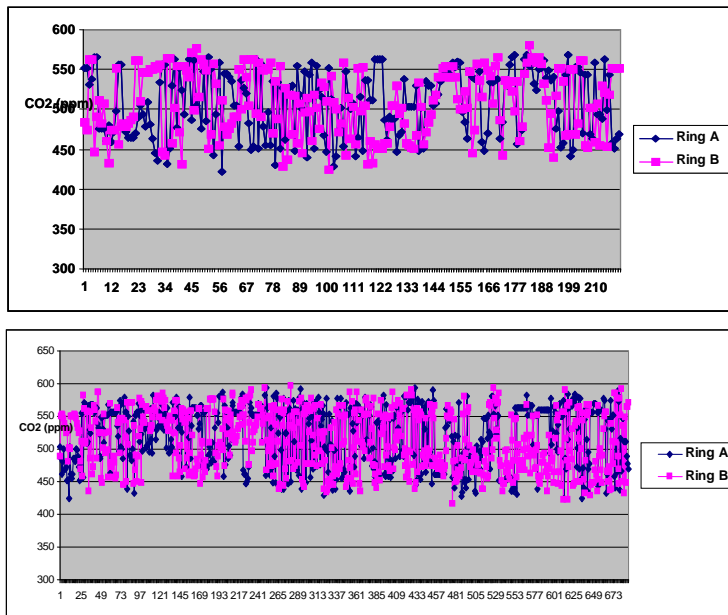
**Fig. 1.Carbon dioxide concentration in FACE rings in (a) kharif & (b) rabi season**
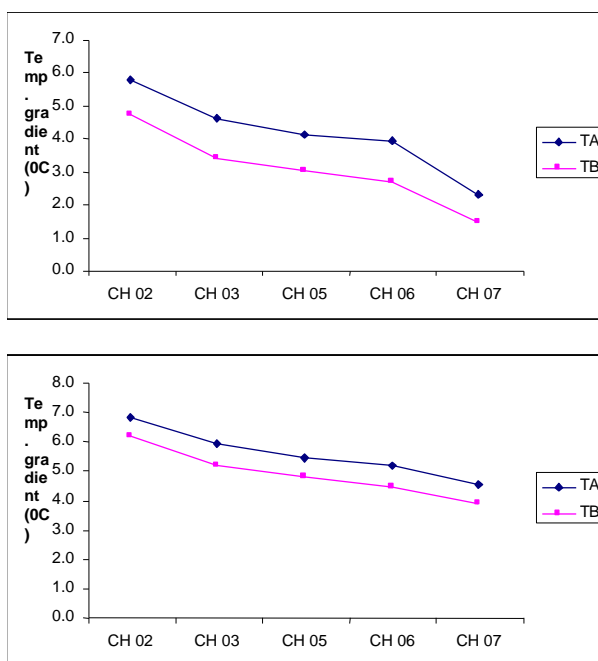
Fig. 2 Temperature gradient in temperature gradient tunnels (TGT) in (a) kharif and (b) rabi season

Effect of elevated temperature on growth and productivity of crops

Three important wet season crops (rice, greengram and soybean) and two dry season crops (potato and chickpea) were grown under temperature gradient tunnels (TGT) equipped with automatic temperature sensors at a particular distance with continuous data logging system to assess the effect of increase in temperature on growth, phenology and yield of these crops. Continuous increase in temperature under TGT caused gradual reduction in biological yield, economic yield and yield components in all these crops, while chickpea exhibited gradual increase in its seed and biomass yield up to 3 ^{0}C increase in temperature and thereafter started to decline. Among the crops, rice which showed highest degree of reduction in grain yield by increasing temperature, was attributed to marked reduction the number of panicles/pot, number of grains/panicle, biological yield and harvest index. This reduction in grains/panicle was mainly due to remarkable increase in spikelet sterility. However, 1000 grain weight was least affected by rise in temperature. Greengram, soybean and chickpea also showed gradual reduction in their economic yield, which was attributed to substantial reduction in biological yield and 1000 seed weight, while seeds per pod was least affected both in greengram and soybean. Harvest index of greengram reduced drastically by increase in temperature, while soybean did not show any decrease in the same under high temperature regimes. Potato yield reduced gradually with rise in temperature owing to reduction in the number of tubers/plant and average tuber size (Fig. 3, 4).
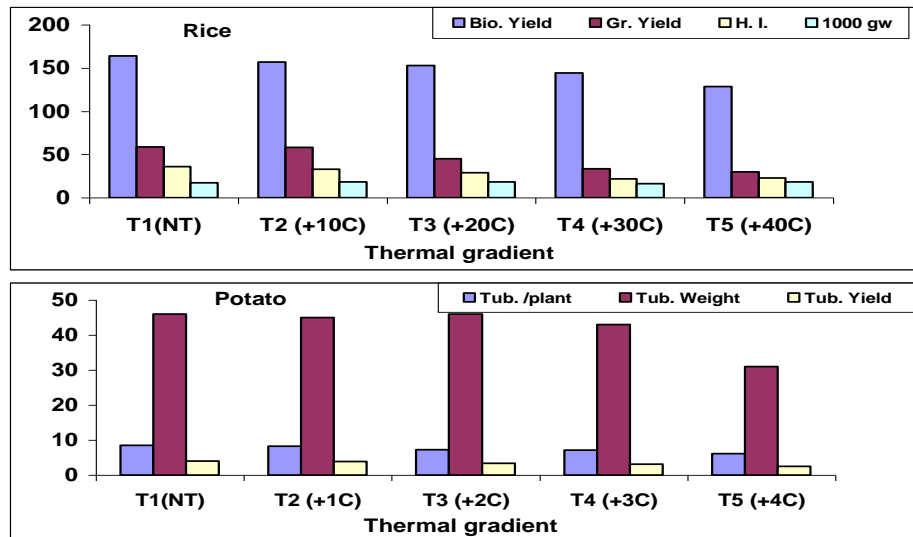

**Fig. 3 Effect of temperature increase on growth and yield of rice (g/pot) and potato (kg/m^2)**
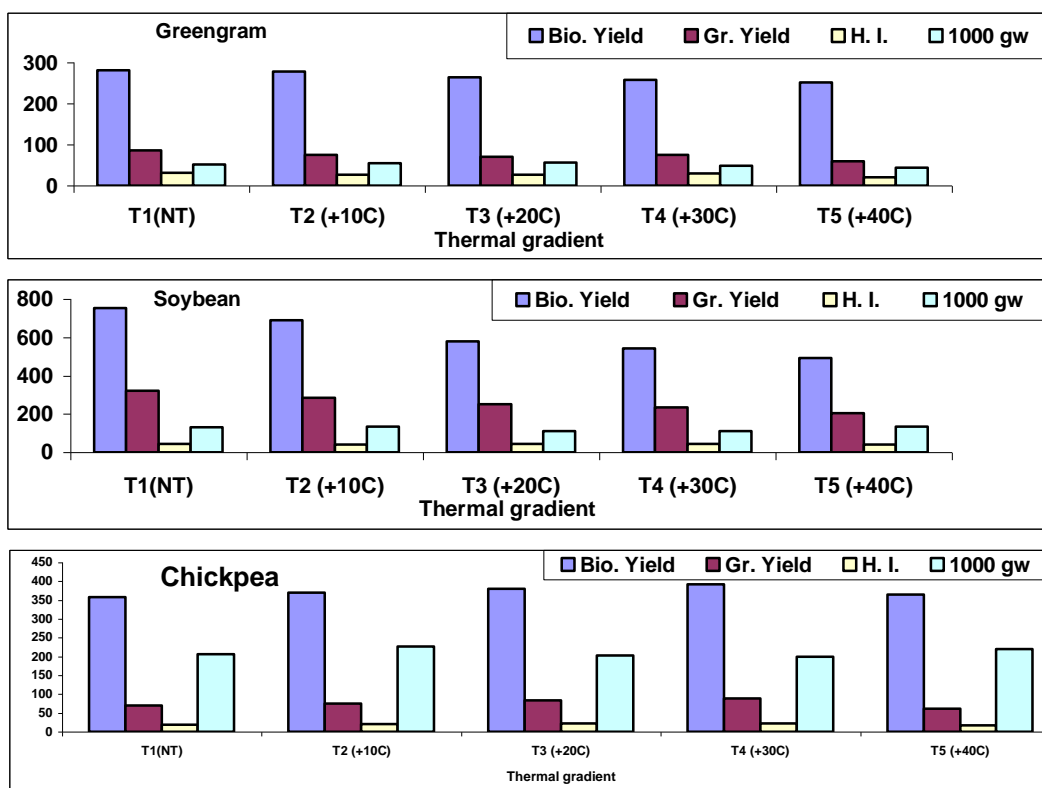
Fig 4. Effect of temperature increase on growth and yield (g/m^2) of soybean, greengram and chickpea

Effect of elevated CO2 on crop growth and yield

Two Kharif crops (greengram and soybean) and two Rabi crops (potato and chickpea) were grown both under ambient (375ppm) and elevated CO_2 (550ppm) conditions using FACE facility to assess the effect of elevated CO_2 level on growth and yield of different crops. Elevated CO_2 increased the yield of greengram, soybean, chickpea and potato substantially (14-22%). Enhancement in crop yield was attributed to marked increase in number of pods per plant and 1000 seed weight in greengram, soybean, chickpea. Increase of tuber yield in potato by CO_2 enrichment was attributed to increase in both the number of tubers/plant and size of tuber. However number of seeds per pod was least affected by CO_2 enrichment (Fig 5,6,7,8).
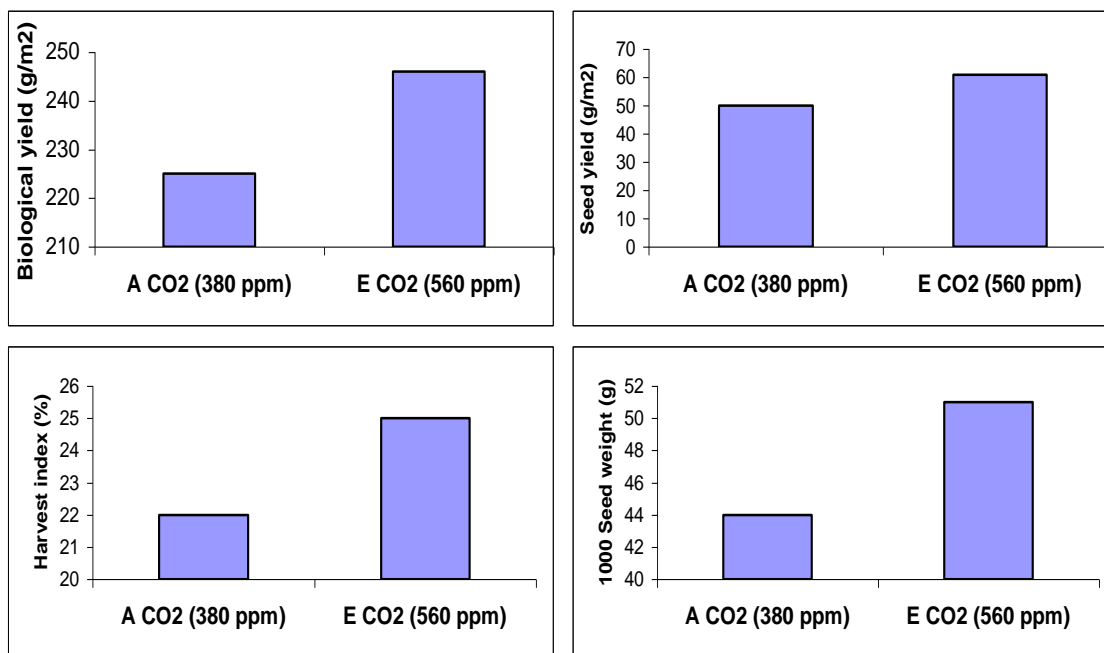
Fig. 5 Effect of elevated CO$_2$ on growth and yield of green gram
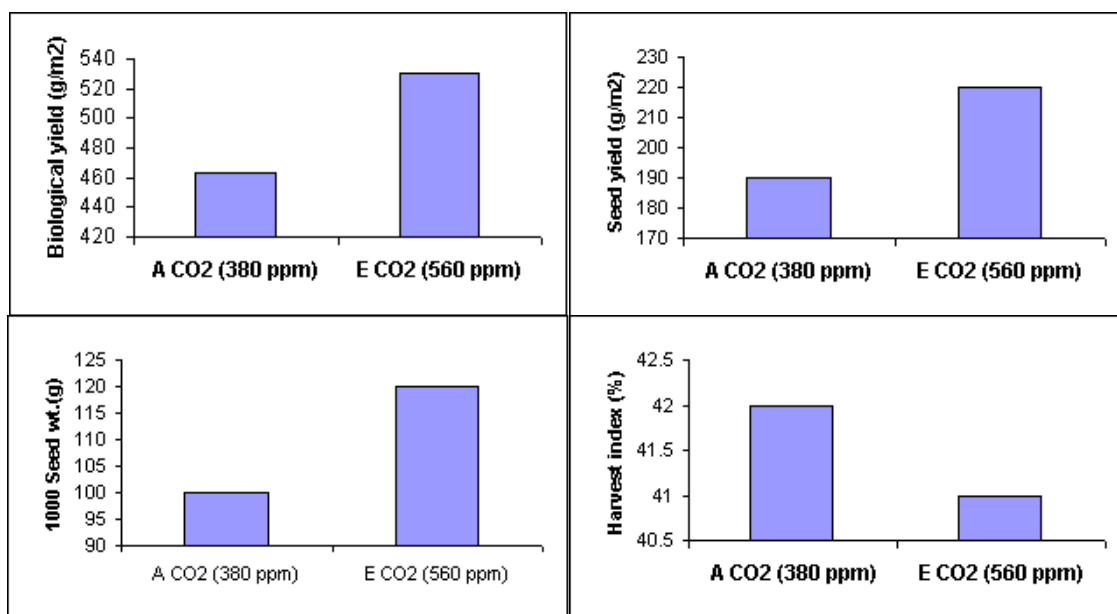
Fig. 6 Effect of elevated CO$_2$ on growth and yield of soybean
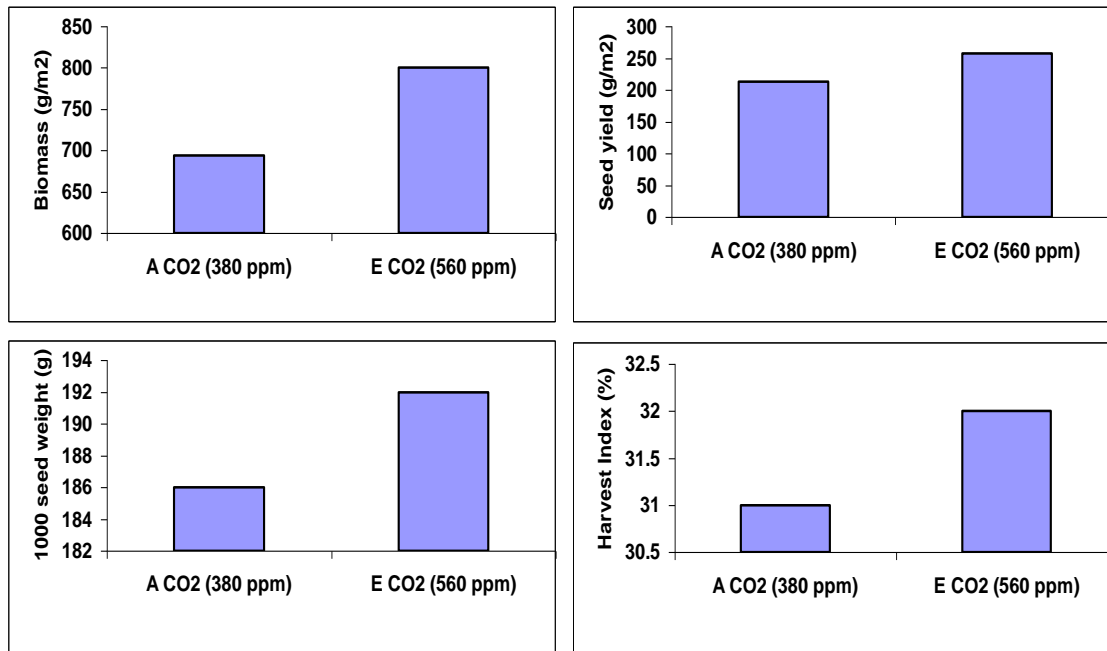
Fig. 7 Effect of elevated CO_2 on growth and yield of chickpea

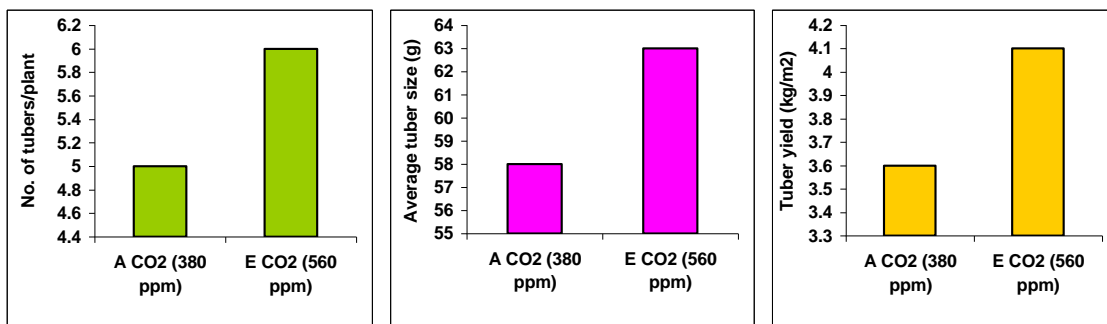**Fig. 8 Effect of elevated CO_2 on growth and yield of potato**

Objective 2. To assess the impact of high day vs night temperature on crop growth and productivity of different crops

Three important Kharif crops (greengram, soybean and groundnut) and three Rabi crops (wheat, chickpea and potato) were grown under elevated temperature during day vs night throughout their growing season. These crops were grown in three polyhouses separately where high temperature during daytime was imposed in one polyhouse by regulating the speed of exhaust fan and, high temperature during nighttime was imposed by closing the fan during nighttime, while normal temperature (near ambient) during day and night was maintained by running the fans throughout day and night. The rise in temperature only during daytime caused marked reduction in growth and yield of all these crops except potato where it was increased, while elevated temperature during nighttime showed enhancement in growth and yield of all these crops except potato which showed marked reduction in tuber yield under such condition. Reduction of crop yield under elevated day temperature was mainly due to marked decrease in the number of pods per plant, and

33

biological yield, while increase in crop yield under high night temperature was attributed to marked increase in biological yield and pods per plant (Fig. 9, 10).
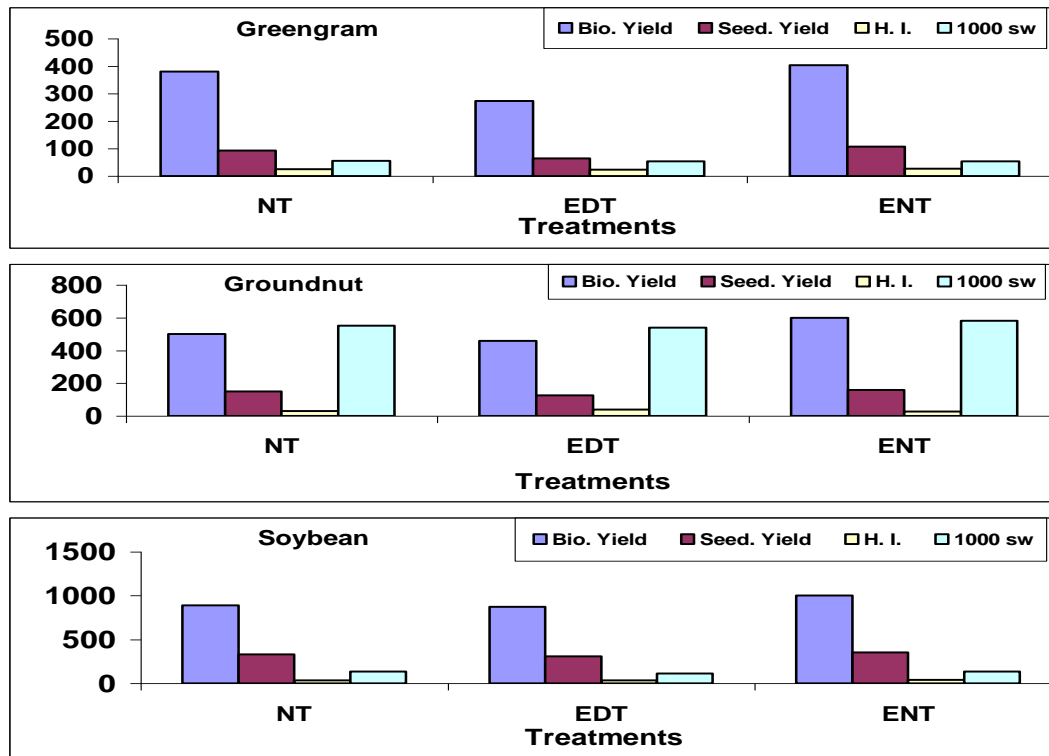
Fig.9 Effect of high day vs night temperature on growth and yield (g/m^2) of green gram, soybean and groundnut
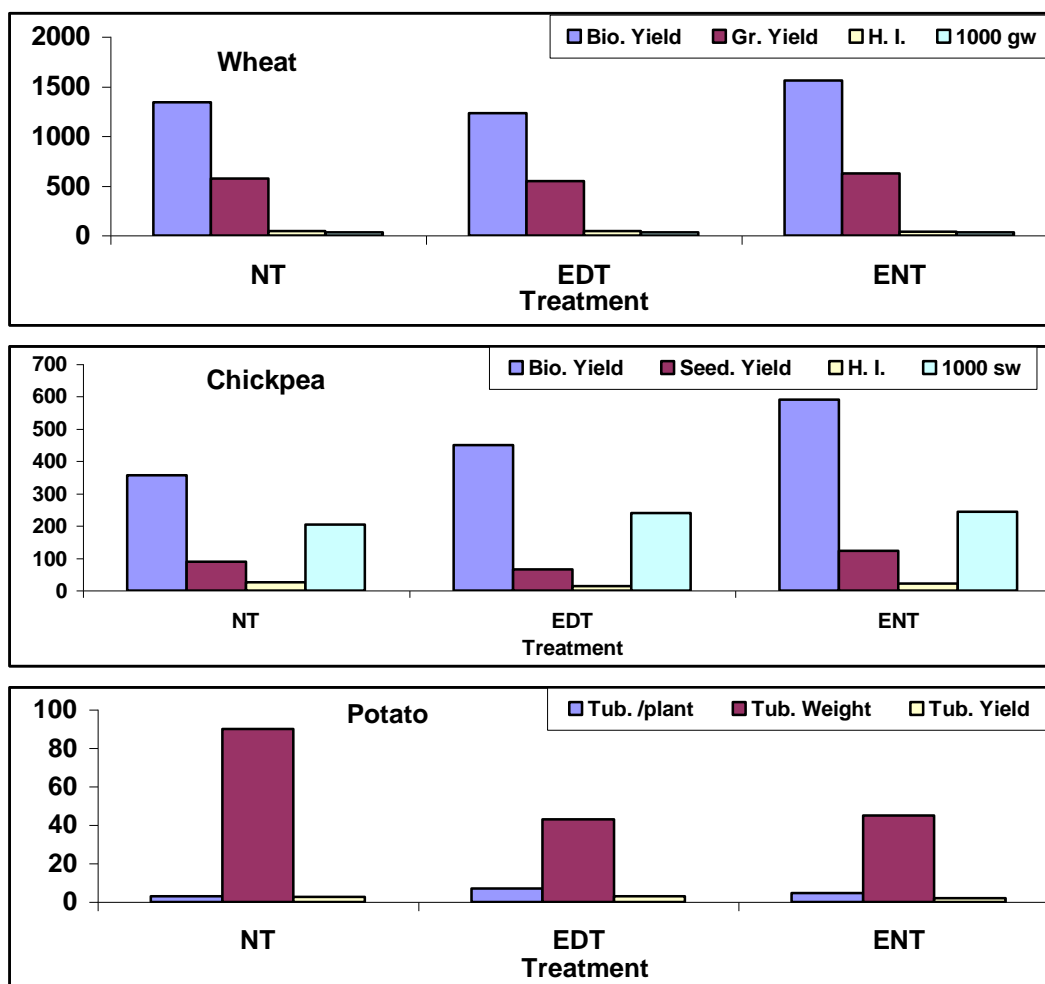
Fig.10 Effect of high day vs night temperature on growth and yield (g/m2) of wheat, chickpea and potato

Objective 3. To assess the impact of high temperature during different growth phases on growth and yield of different crops

Four important crop species namely wheat, chickpea, mustard and pigeonpea were subjected to elevated temperature during their different growth phases viz., vegetative, reproductive and ripening phases to assess the impact of high temperature during different growth phases of crops on their growth and productivity. Wheat crop showed greater sensitivity to elevated temperature during ripening phase followed by vegetative and reproductive growth phases. High temperature stress caused maximum reduction in seed yield of chickpea during vegetative growth phase followed by reproductive growth phase. The reduction in grain yield was attributed to marked reduction in biological yield and partitioning to grain. Compared to economic yield, vegetative shoot (straw) yield was less affected by high temperature in chickpea. In pigeonpea, high temperature stress throughout its growing period caused drastic reduction in seed yield (60%), while enhanced the growth of its vegetative shoot, which resulted in marked reduction of its

harvest index. However, high thermal stress during post flowering phase reduced the seed yield by 35%, biological and straw yield by 33 % and did not show any reduction in harvest index. Mustard showed substantial reduction in seed yield by high temperature stress during vegetative and reproductive growth phases. Flowering duration was found more sensitive to high temperature as compared to vegetative growth phase (Fig. 11,12).
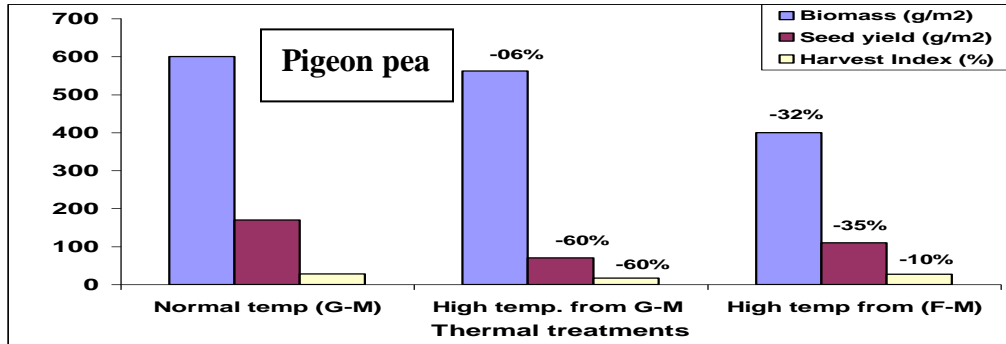
Fig 11. Effect of high thermal stress during different growth phases on growth and yield of pigeonpea
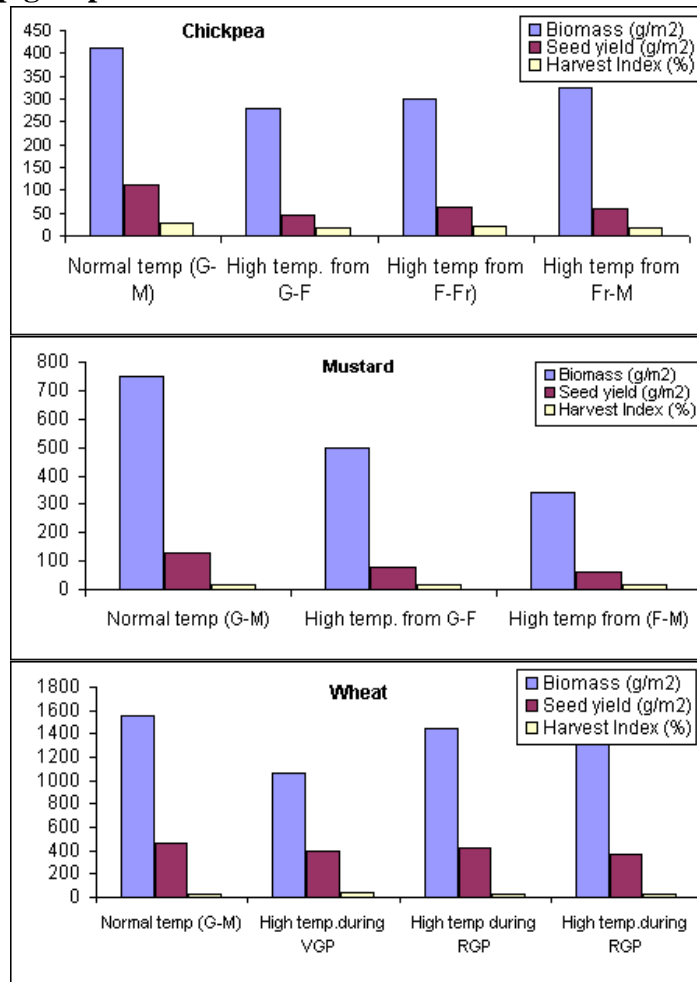
Fig 12. Effect of high thermal stress during different growth phases on growth and yield of different crops

Objective 4. To assess the impact of elevated temperature and CO2 on nutritional and seed quality of different crops

Effect of elevated temperature on quality characters of crops
Potato: Potato was grown in a polythene temperature gradient tunnel (TGT) and was exposed to elevated temperature of 4^0C in steps of approximately 1^0C. Final harvest was evaluated for various quality traits. With each degree increment in temperature, sugar content increased marginally (0.1 to 0.5%) whereas starch content decreased significantly (0.5 to 2.5%). Protein content increased and that of tuber density declined with increase in temperature (Fig.13).
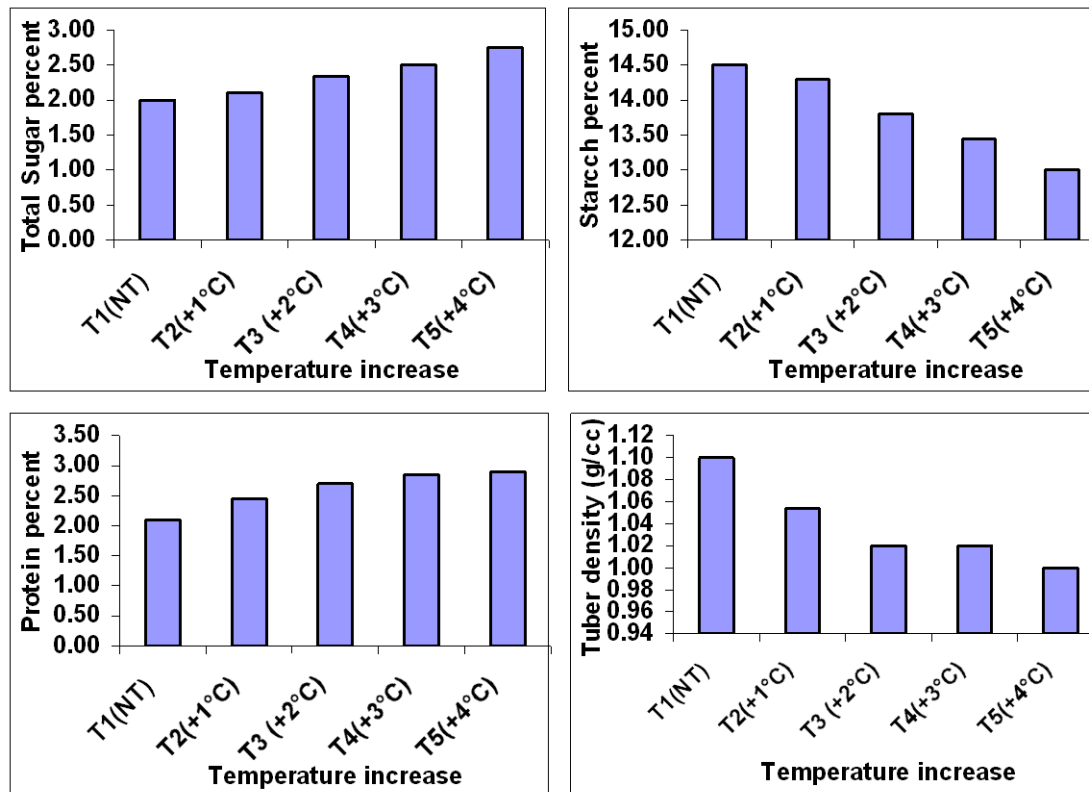
Fig.13. Impact of gradual increase in temperature on quality traits of potato

Soybean: In soybean (Var. DS 9814), with increase in temperature, protein content increased from 33.5 to 34.7% whereas oil content decreased until 2^0C increase and then reached the same level as that of control with further increase in temperature Fig 14).

Rice: In rice (Var. Pusa 44), gradual increase in temperature reduced amylose content by 2% and no particular trend was observed for germination of the harvested seeds. However, seedling vigour reduced drastically by 25 to 40% due to elevated temperature (Fig.15).
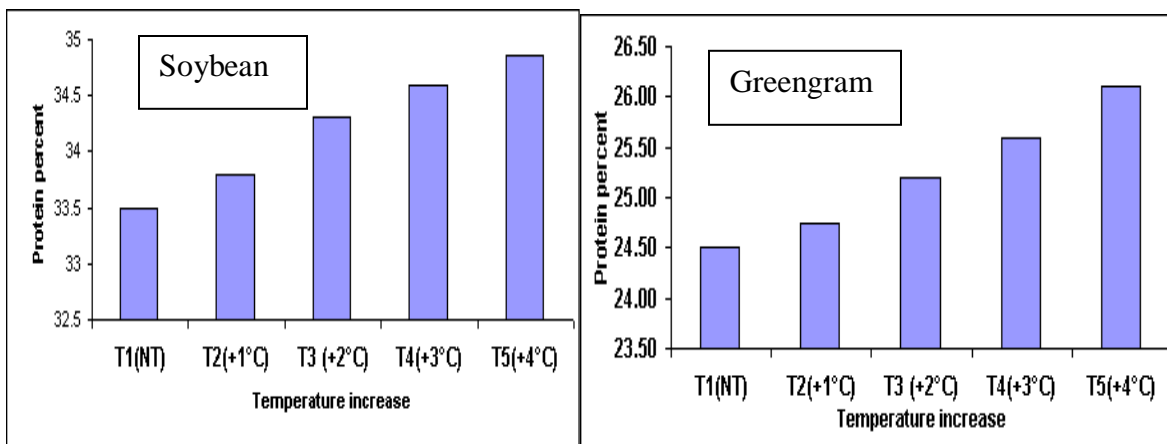
Fig.14 Effect of temperature gradient on protein content of soybean and greengram
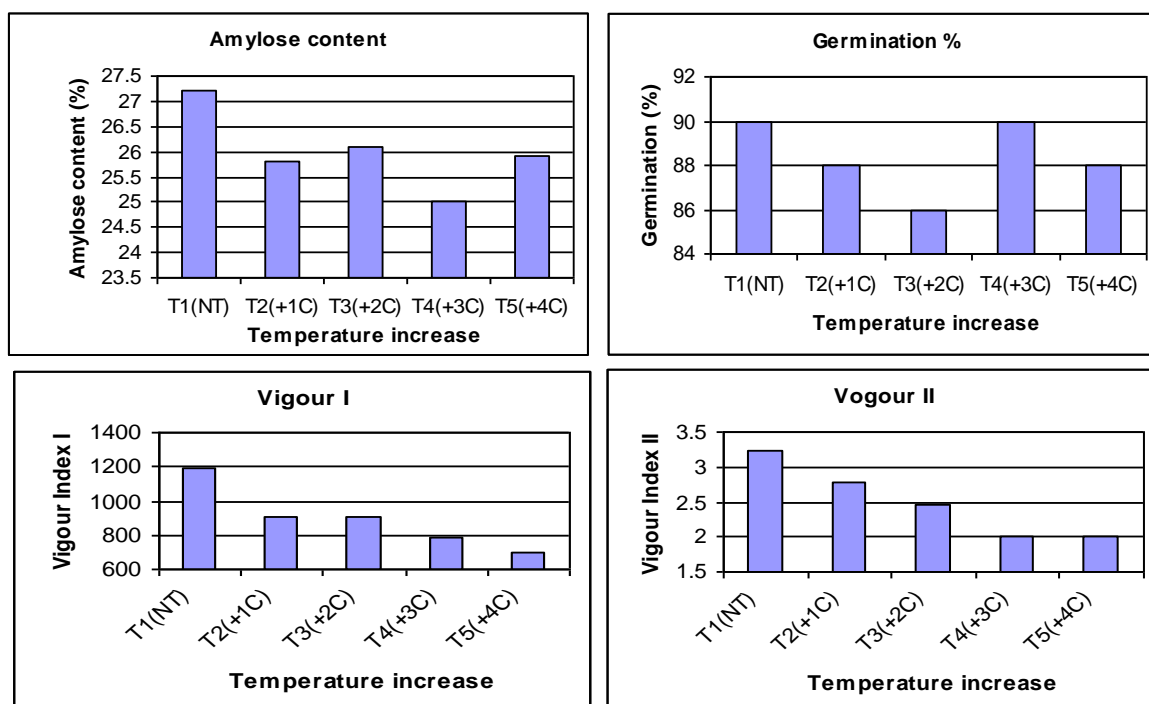
Fig.15. Impact of temperature gradient on grain & seed quality of rice

Greengram: In green gram (var. Pusa Vishal), an increase in temperature of 4^0C increased the protein content by 1.5% in TGT experiment (Fig 14). Seed quality as measured by germination and vigour were not affected until a temperature rise of 2^0C. But an increase of 3 to 4^0C decreased both germination and vigour of green gram seeds (Fig.16).
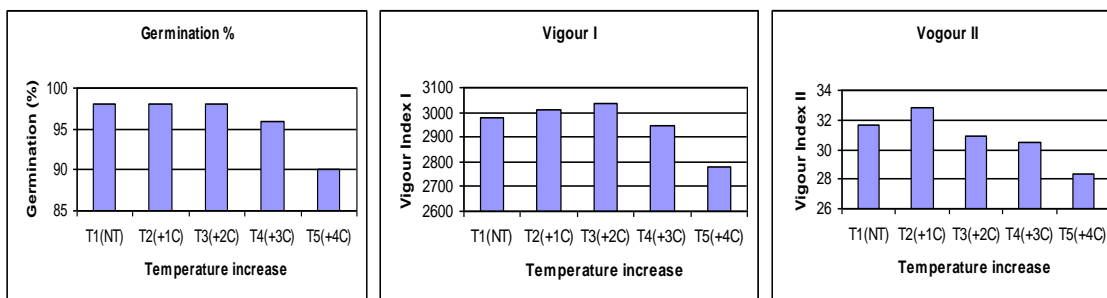
Fig. 16. Impact of temperature gradient on seed quality of green gram

Impact of elevated day/night temperature on quality of some crops

In a controlled environment experiment using polythene tunnels, temperatures were raised only during day or night and compared with the controlled condition where day and night temperatures were kept optimum. Mean monthly maximum, minimum temperatures during the period of experimentation are given below for the three treatments. On an average, day temperature was increased by 5^0C and night by 3^0C compared to control.

In potato, quality characters were not affected except for a marginal decrease in both sugar and starch content of tubers (Fig 17). Protein content in green gram declined by 1.5% only under elevated night temperatures (Fig 18), whereas protein content in soybean decreased by 2 to 3% under both elevated day and night temperatures (Fig.18). In soybean, oil content decreased only under elevated day temperatures. The seed quality analysis of green gram showed that germination and vigour are adversely affected only under elevated day temperatures whereas elevated night temperatures improved seedling vigour compared to control (Fig. 19)
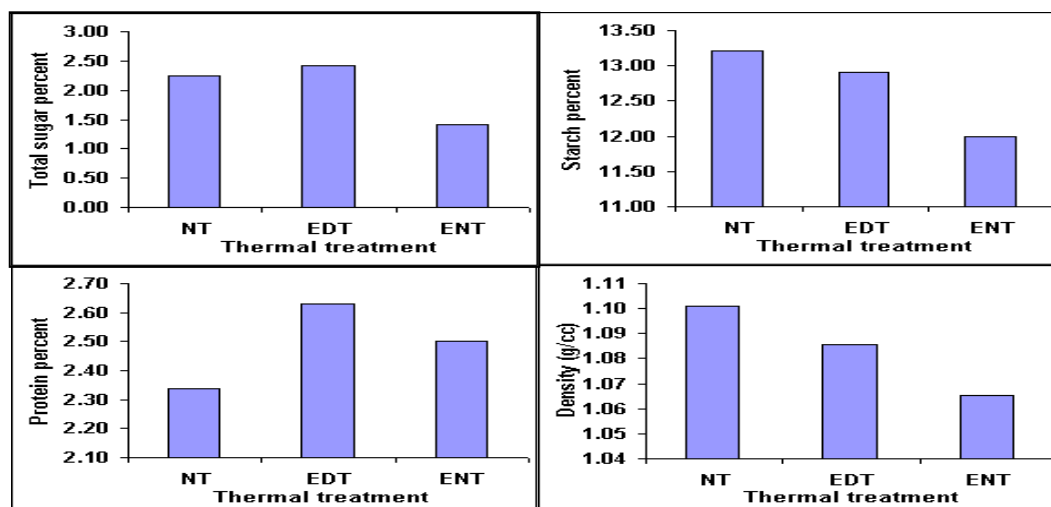
Fig. 17. Effect of high day vs night temp. on quality traits of potato tubers
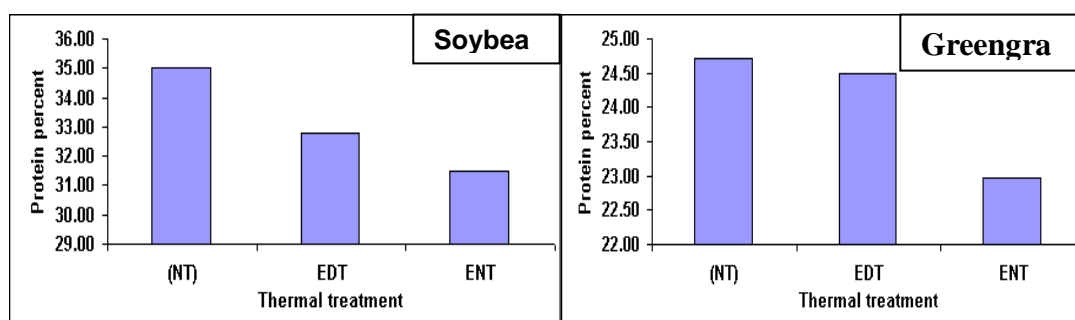
Fig. 18.Effect of high day vs night temp. on protein content of soybean and greengram seeds
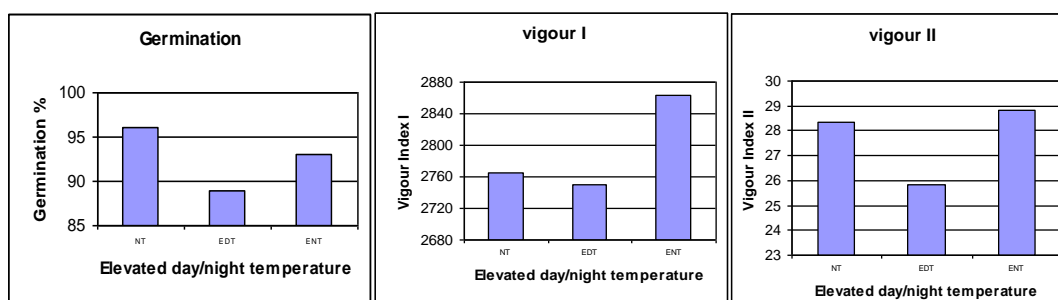
Fig.19. Impact of elevated day/night temperature on seed quality of green gram

Impact of elevated CO_2 on quality of some crops

FACE experiments were conducted where plants were grown under elevated CO_2 of 560ppm and compared with those grown in ambient levels of 380ppm. In potato, tubers from elevated CO_2 showed marginal increase in both sugar and starch content and decrease in protein content. The density of tubers remained unchanged. In soybean there was drastic reduction of about 3% in protein content of seeds while the decline was 1% in green gram seeds when plants were grown under elevated CO_2. However, the oil content in soybean increased marginally (Fig 20). Elevated CO_2 adversely affected quality of green gram seeds. Germination was reduced by nearly 10% and vigour II of seedlings based on dry weight was reduced by 25% (Fig.20).
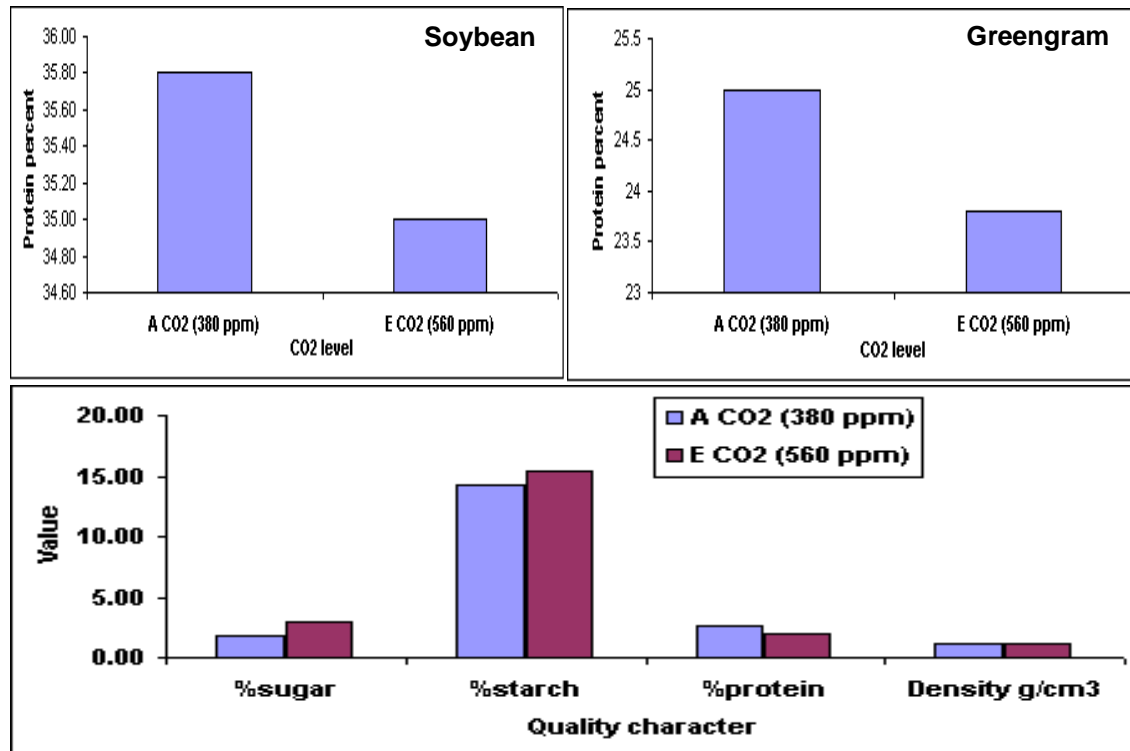
Fig. 20. Effect of elevated CO$_2$ on quality characters of soybean and greengram seeds and potato tubers

Objective 5. To assess the impact of elevated temperature on GHG emission and measures for their mitigation

Measurement of carbon dioxide and nitrous oxide emissions from soil was carried out in temperature gradient tunnels to study the impact of elevated temperature on the greenhouse gases emissions. The soil temperature inside the temperature gradient tunnel ranged from 20.2 to 38.8 ^{o}C over the study period and was on an average 3.6^{o}C higher than the ambient soil temperature over a period of 100 days. The emissions of carbon dioxide under elevated temperature did not follow any pattern in the kharif season and varied from 0.12 gm^{-2}d^{-1} to 1.8 gm^{-2}d^{-1} in soil having organic carbon content of 0.33% (Fig 21.). The cumulative flux of carbon dioxide did not significantly increase with an average increase of temperature by 3.6^{o}C over a period of 100 days. The nitrous oxide emission from fertilized soil under elevated temperature was higher on most of the sampling days over the ambient. The cumulative flux of N$_2$O-N from fertilized soil over 100 days increased by 21% over the ambient soil conditions (fig 22.).

In the rabi season the emissions of carbon dioxide under elevated temperature inside the temperature gradient tunnels were on many days higher than under ambient soil conditions. The temperature inside the temperature gradient tunnel ranged from 6.7 to 22.5 ^{o}C over the study period and was on an average 4.5 to 6.8^{o}C higher along the temperature gradient tunnel as compared to the ambient temperature. On an average the

41

temperature was found to be 5.2^{o}C higher in the TGT as compared to the ambient. The emissions of carbon dioxide from soil under elevated temperature were on many days higher than from soil under ambient conditions. The emissions of carbon dioxide under elevated temperature varied from 0.18 gm^{-2}d^{-1} to 2.14 gm^{-2}d^{-1} in soil having organic carbon content of 0.3%. The cumulative flux of carbon dioxide was found to be 12% higher inside the TGT over the ambient over a period of 115 days.
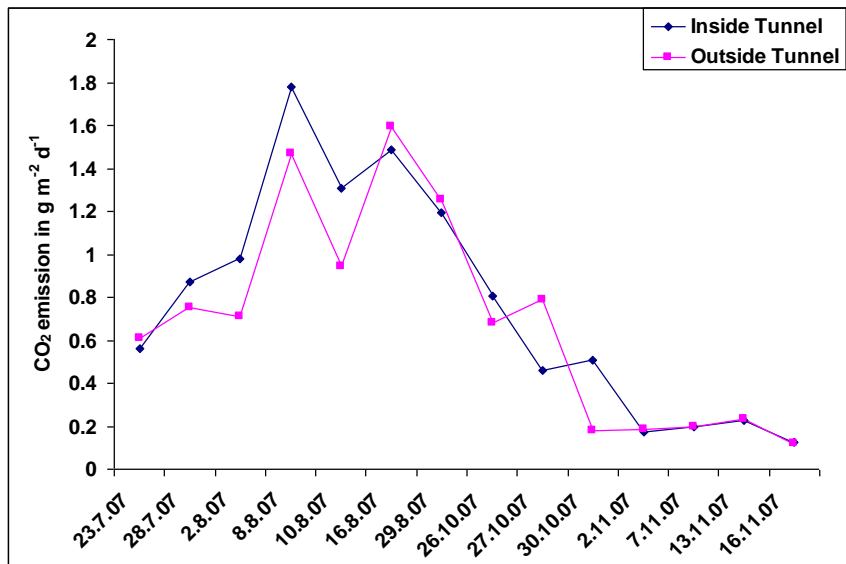
Fig.21. Carbon dioxide emissions from soil under elevated temperature in temperature gradient tunnel
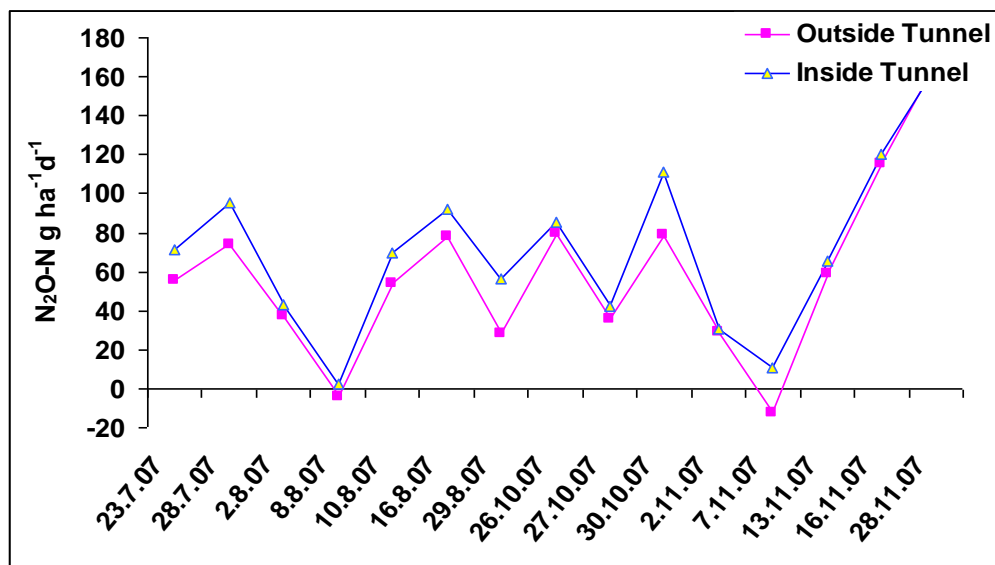
Fig.22. Nitrous oxide emissions from fertilized soil under elevated temperature in temperature gradient tunnel

Objective 6. To assess the impact of high temperature on insect pest dynamics in crops

Development and validation of insect population dynamics simulation model
Generic insect population dynamics models were developed for holometabolous, hemimetabolous and viviparous type of insect life cycles. Holometabolous life cycle involves egg, larval, pupal and adult insect stages while hemimetabolous insects have egg, nymphal and adult stages. On the other hand viviparous insect like most of aphid species have only nymphal and adult stage. These models are based on the concept of thermal time and threshold of development. Insect population converts from one development stage to the next stage depending upon the available effective temperature in relation total thermal requirement of that stage. Effective temperature is calculated by deducting threshold of development from the average daily temperature. Biological parameters such as fecundity and sex ratio, and biotic and physical mortality factors have been included in the models. The effect of physical factors viz., temperature and humidity was accounted for based on their favourable range for an insect species. Thermal time was corrected for the non linear effect of extreme temperature conditions.

Model validation
Holometabolous model: This model was adapted for maize stem borer, *Chilo partellus*. Thermal time for egg, nymphal, pupal and adult stage was taken as 51, 492, 45 and 20 degree days (DD), respectively whereas corresponding thresholds of development were 15.3, 12.5, 17.7 and 12 ^{o}C. Infertility accounted for 21% egg mortality while larval mortality due to bio-agents was included as 93%. On the other hand, pupal mortality happened to be very low. Optimum average temperature range for the pest was taken as 21-30 ^{o}C. The model was validated against the pest population data of three generations observed during 1991 under Delhi conditions. Number of observed and simulated eggs and larvae was very close during the three generation. On the other hand, observed and simulated pupal and adult populations were proximal during I and II generations but there was some departure between observed and simulated number of these stages during III generation (Fig.23).

Hemimetabolous model: This model was adapted for rice gundhi bug, *Leptocorisa acuta*. Thermal time for egg, nymphal and adult stage was taken as 90, 350 and 30 DD, respectively whereas corresponding thresholds of development were 12, 10 and 10 ^{o}C. Infertility and bio-agents accounted for 50% egg mortality while nymphal mortality due to bio-agents was 75%. Optimum average temperature for the pest was taken as 20-31 ^{o}C. The model was validated against the light trap catch data on adult bug population obesrevd at Pattambi during 2001-2004. Number of observed and simulated adults was found to be close (Fig. 24).

Vipiparous model: This model was adapted for mustard aphid, *Lipaphis erysimi*. Thermal time for nymphal and adult stage was taken as 129 and 20 DD, respectively whereas corresponding thresholds of development were 12 ^{o}C for both the stages. Intensity of bio-agents was introduced as a function day of the year. Optimum average temperature for the pest was taken as 14-16 ^{o}C. The model was validated against the aphid population

data observed during different years (Fig. 25). The model simulated the population trend in terms of population rise and decline correctly, but there were differences between observed and simulated peak populations during different years.
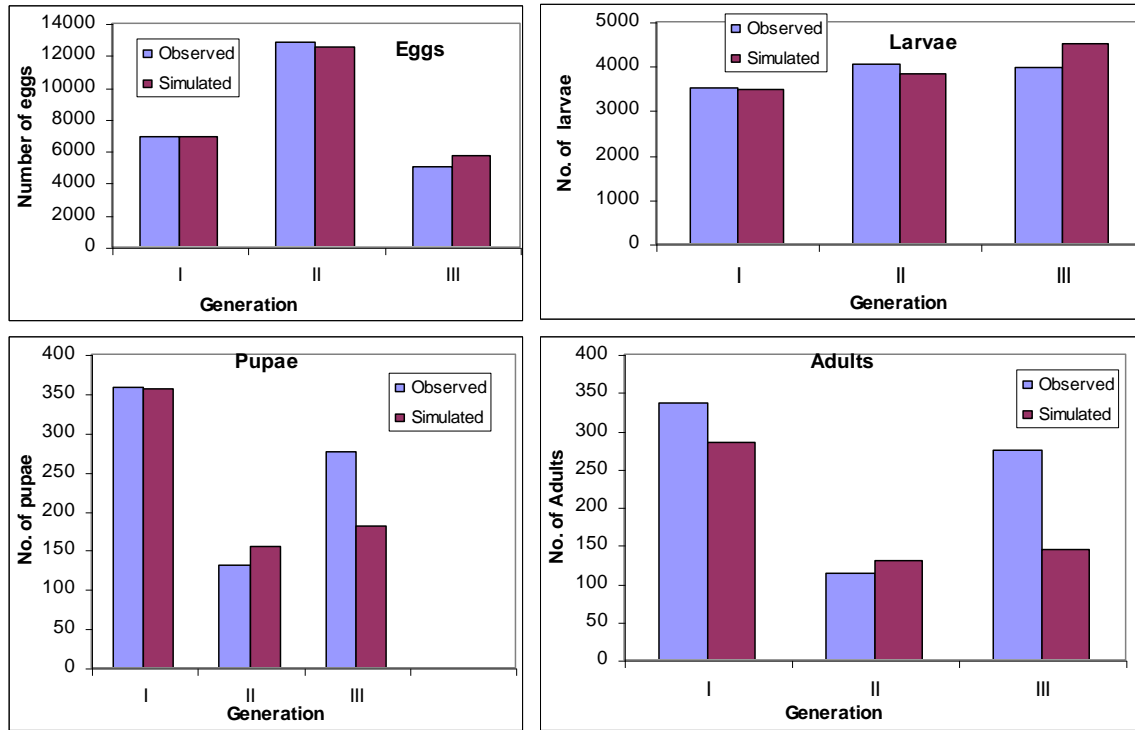
Fig. 23 Observed and simulated population of maize stem borer, *Chilo partellus* in different development during three generations
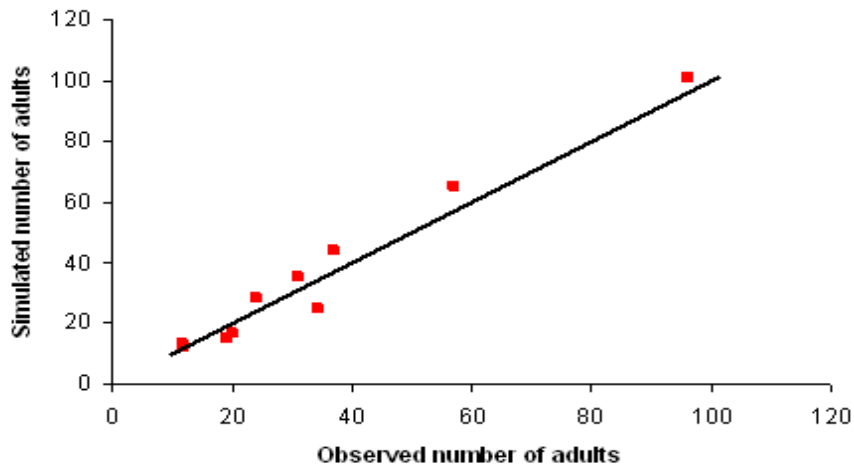
Fig. 24 Observed and simulated population of adult rice gundhi bug, *Leptocorisa*
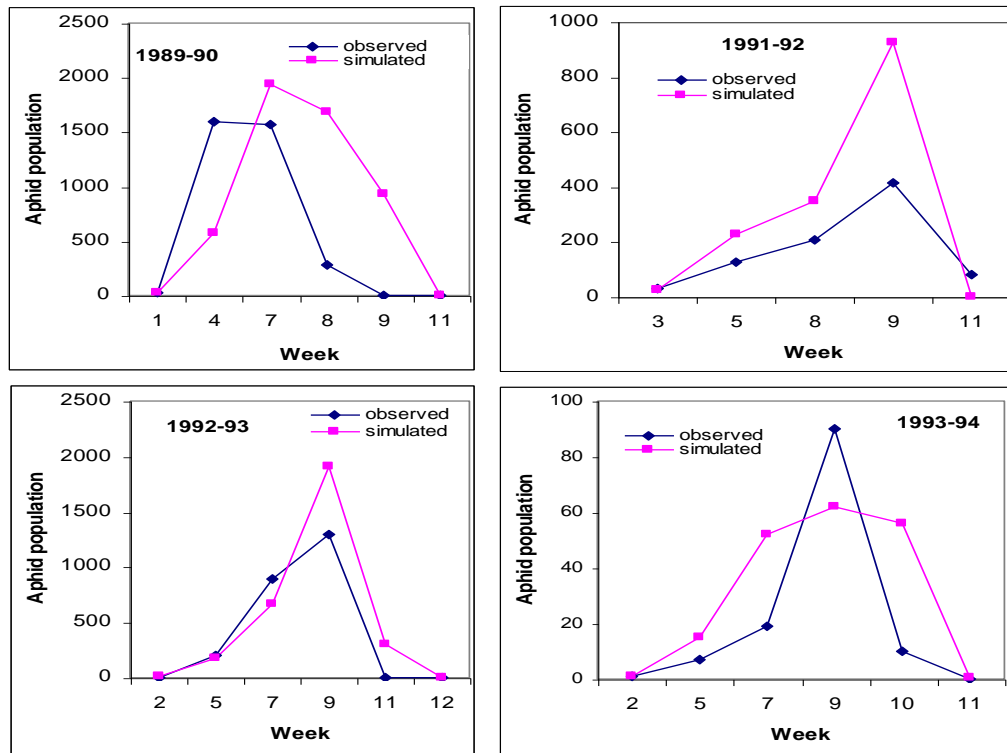
Fig. 25 Observed and simulated population of mustard aphid, *Lipaphis erysimi* during different years

Effect of high temperature on physiological characteristics and yield of chickpea (*Cicer arietinum* L.) cultivars.

Two chickpea cultivars (Pusa 1053 and Pusa 1108) were raised in earthen pots in pot culture of the Division of Plant Physiology. Recommended cultural practices were followed. One set of plants was grown under natural environment (ambient temperature) while other set of plants was grown inside a polycover and exposed to high temperature (ranged between 3-4 ^{o}C, above ambient temperature) from germination till maturity of the crop. A third set of plants was exposed to high temperature during flowering stage and fourth set was exposed to high temperature only during pod filling stage by transferring the pots inside poly cover. Observations were recorded on membrane stability index, carbohydrates and proline at vegetative, flowering and pod filling stages and yield attributes were recorded at harvest of the crop.

Membrane stability index (MSI) varied significantly at different stages of growth in both the cultivars. At vegetative and pod filling stage, no significant changes occurred in MSI under high temperature. However, at flowering stage both the cultivars showed significantly higher MSI due to elevated temperature. No significant effect of high temperature occurred on concentration of total sugars in both the cultivars at vegetative and flowering stage but Pusa 1108 showed significant reduction n total sugars during pod filling stage under high temperature. Proline content was significantly higher in high temperature grown chickpea plants of cultivar Pusa 1108 while no significant changes occurred in Pusa 1053 (Fig. 24). The effect of high temperature on yield attributes varied among both the cultivars exposed to high temperature throughout the growth period. No significant changes occurred in yield attributes of Pusa 1108 due to exposure to high temperature either throughout the growth period or at different stages. On the other hand, Pusa 1053 plant exposed to high temperature only during flowering stage responded positively and produced higher seed number and grains per plant compared to the plants grown under high temperature throughout the growth period and exposed only during pod filling stage (Table 1). This study concludes that 3-4 ^{o}C increase in temperature may not affect the yield of chickpea plants and even short spells of increased temperature particularly during flowering period may have positive effect on growth and development. However, further studies are required to confirm these findings particularly under field conditions.

Table1: Effect of elevated temperature (3-4 ^{o} C above ambient) on yield attributes of chickpea cultivars. T_0= Ambient temperature, T_1= Exposure to elevated temperature throughout the growth period, T_2= Exposure to elevated temperature during flowering stage and T_3= Exposure to elevated temperature during pod filling stage.

Variety	Temperature levels	No. of pods plant^{-1}	No. of grains plant^{-1}	Grain weight plant^{-1}	1000 Grain weight	Total dry weight plant^{-1}
PUSA 1053	T_0	28	18	5.01	290.2	15.22
	T_1	28	22	6.07	290.8	16.0
	T_2	43	35	9.09	292.8	19.44
	T_3	33	21	5.37	299.6	14.7
PUSA 1108	T_0	35	32	8.82	283.8	19.9
	T_1	36	34	8.54	312.5	20.22
	T_2	40	37	9.97	311.9	22.33
	T_3	35	27	8.49	333.7	21.0
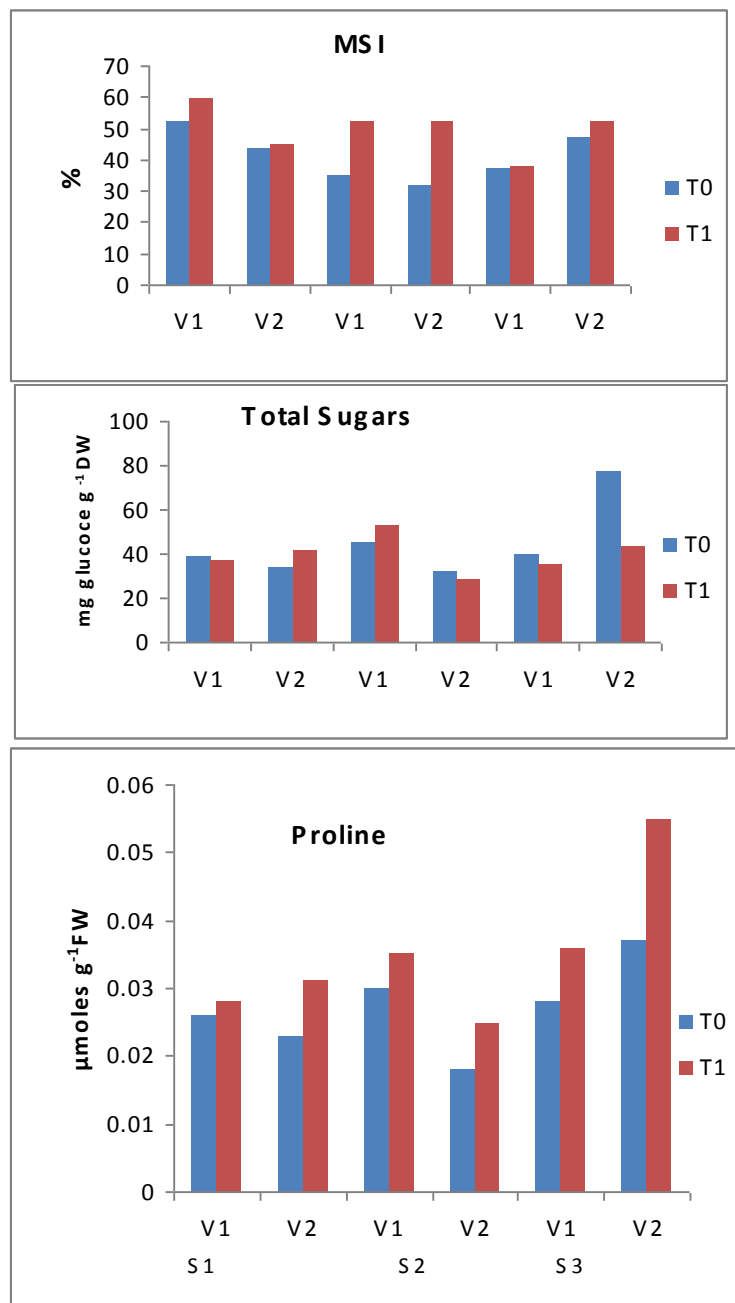
Fig. 26: Effect of elevated temperature (3-4 ^{o} C above ambient) on membrane stability index, total sugars and proline content of chickpea cultivars. T_O= Ambient temperature, T_1= Exposure to elevated temperature throughout the growth period, T_2= Exposure to elevated temperature during flowering stage and T_3= Exposure to elevated temperature during pod filling stage. V1=Pusa 1053 and V2=Pusa1108. S1=Vegetative Stage, S2= Flowering Stage and S3=Pod filling Stage.

Impact of high temperature on chickpea genotypes exposed to high temperature at flowering stage

Chickpea genotypes were exposed to elevated temperature $(30/20^0C)$ in a growth chamber at 50% flowering stage for two different periods. Day/night cycles for temperature and photoperiod were 12h day and 12h night. All plants were maintained at $70\pm5\%$ relative humidity and photosynthetically active radiation (PAR) of 300 µmol m$^-$^{2}s^{-1}. One set was exposed to the elevated temperature for 5 days and the other for ten days. One set was kept under ambient temperature conditions of $25/20^0C$. The control plants were also removed from the chamber along with the stressed plant after the exposure. Exposure of seven days to high temperature did not affect the yield of both the genotypes whereas a longer exposure of fourteen days of high temperature resulted in enhanced yield of 2.2 and 1.8 fold in Pusa 1053 and Pusa 1108 respectively. This increase in yield was attributed to increase in biomass and no. of pods/plant. High temperature reduced the sterility of pods under both treatments. This study shows that an exposure of high temperature for a fortnight at flowering stage had a beneficial effect on growth and yield of the crop. This effect was more pronounced in Pusa 1053 than Pusa 1108.
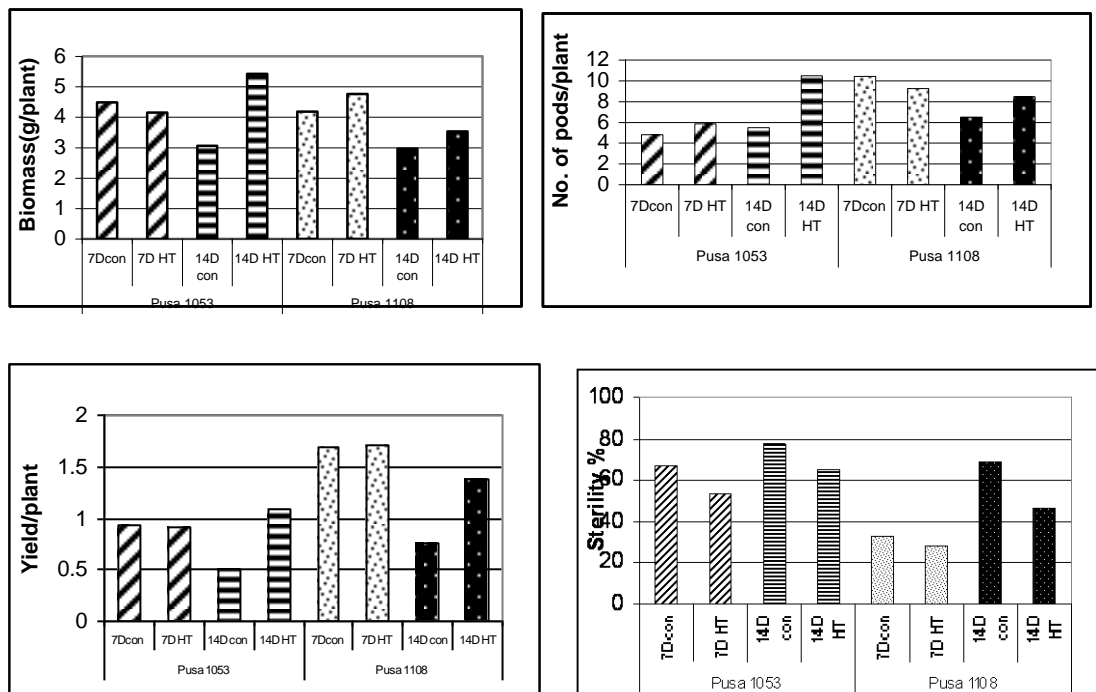
Figure 27: Response of chickpea genotypes exposed to high temperature at flowering stage

49

Central Plantation Crop Research Institute, Kasaragod

Objective 1: To validate the coconut model in different agro-climatic regions

During the year, the climate change module is incorporated into the coconut simulation model and model was refined. Model was calibrated and validated to different agro-climatic zones. The validation results indicated very good agreement with observed values with R^2 of 0.86 for nut yield (Fig. 1a) and R^2 of 0.955 for dry matter production and partitioning (Fig 1b).
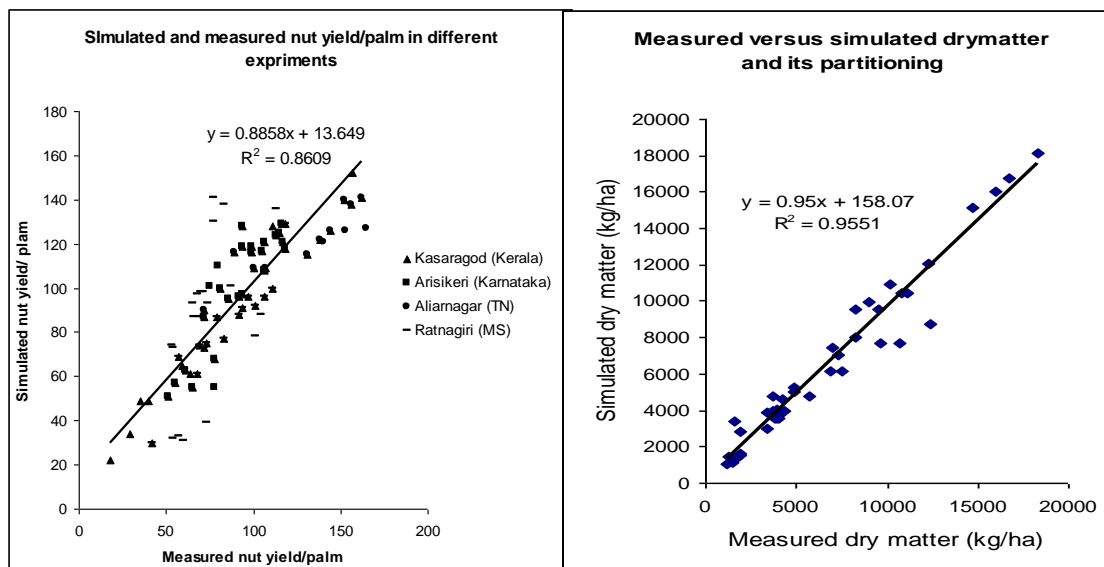
Fig 1. Simulated and measured (a) nut yield and (b) dry matter production and partitioning in coconut.

Using the validated model, potential yields, yields in irrigated and rainfed conditions were simulated for different agroclimatic zones. Coconut productivity shows wide variations across agro-climatic zones and agronomic management levels. Simulated potential TDM production varied across the agro-climatic zones from around 52 t.ha^{-1}.year^{-1} in central southern plateau and hill zone of Karnataka to 62 t.ha^{-1}.year^{-1} at south of southern plateau and hills zone of Tamil Nadu (Table 1). These two locations are interior in lands and had lots of sunlight available for plant growth. However, temperatures in maidan parts of Karnataka (Arisikeri area) are either very high during April to June months or low during December and January months thus lowering the possible potential dry matter production. On the other hand in Tamil Nadu areas, temperatures are more conducive for longer periods for better growth and dry matter production. In areas located on west coast of India, the potential dry matter production was almost similar at 55 t.ha^{-1}.year^{-1}. These areas have adequate sunlight for most part of the year except during rainy season with suitable and stable temperatures.

Table 1: **Coconut potential yields and yields in irrigated and rainfed conditions in different agro-climatic zones**

Condition	Stem + dead inflorescence weight (Kg/ha/year)	Leaf dry weight (Kg/ha/year)	Nut dry weight (Kg/ha/year)	Total dry matter (Kg/ha/year)
Kasaragod (Kerala)				
Rainfed	1166	3019	3871	8056
Irrigated with full fertilizer	4715	12215	15660	32588
Potential	8042	20865	26750	55658
Arisikeri (Karnataka)				
Rainfed (with life saving irrigation)	2306	6008	7703	16018
Irrigated with full fertilizer	4929	12843	16466	34238
Potential	7518	19596	25122	52236
Aliyarnagar (Tamil Nadu)				
Rainfed (with life saving irrigation)	2003	5140	7202	14400
Irrigated with full fertilizer	5295	13629	17473	36398
Potential	9013	23219	29768	61998
Ratnagiri (Maharastra)				
Rainfed	1449	3261	4180	8648
Irrigated with full fertilizer	5083	13213	16940	35237
Potential	7845	20393	26145	54383

Potential yields varied from 25 to 30 $t.ha^{-1}.year^{-1}$ depending on the agro-climatic zone (Table 1). Results indicate higher productivity potential in eastern Tamil Nadu. In this location well managed plantation also yield higher than any other coconut growing location considered for the study. Nut yields in maidan parts of Karnataka are higher as in this location the rainfall distribution is better even though it is a low rainfall zone. However, in this area the plantations require life-saving irrigation during summer. These two factors caused higher yields in Arisikeri area under partial rainfed conditions. In two locations on west coast viz., Kasaragod (in Kerala) and Ratnagiri (in Maharastra) had very low yields as these plantations are pure rainfed grown. In this area the rainfall distribution is concentrated to June to September months and from January to May plantations face dry period thus reducing the yields, apart from this reduced Sun shine during rainy period affected the potential TDM and potential yield. Estimation of potential yields indicates that higher yields can be obtained in coconut plantations in India with better agronomic management particularly in Tamil Nadu.

Objective 2: Study the impact of different scenarios of climate change on coconut in different agro-climatic zones using simulation model

Sensitivity analysis for CO_2 and temperature was also done using simulation model. Results indicated that the coconut productivity is affected more in east coast with increase in temperature even by 1^oC (Fig 1). On the other hand, in west coast the yields are increased with increase in temperature up to 4^oC. Prevalence of higher temperatures, particularly during summers, in east coast may be one of the reasons for reduced daily growth rates (Fig 3) in this area thus reducing the overall annual yield.

Fig 2: Relative impacts and thirty years mean influence of temperature and CO_2 on coconut yield in west coast represented by Kasaragod dist and east coast represented by Godavari dist.
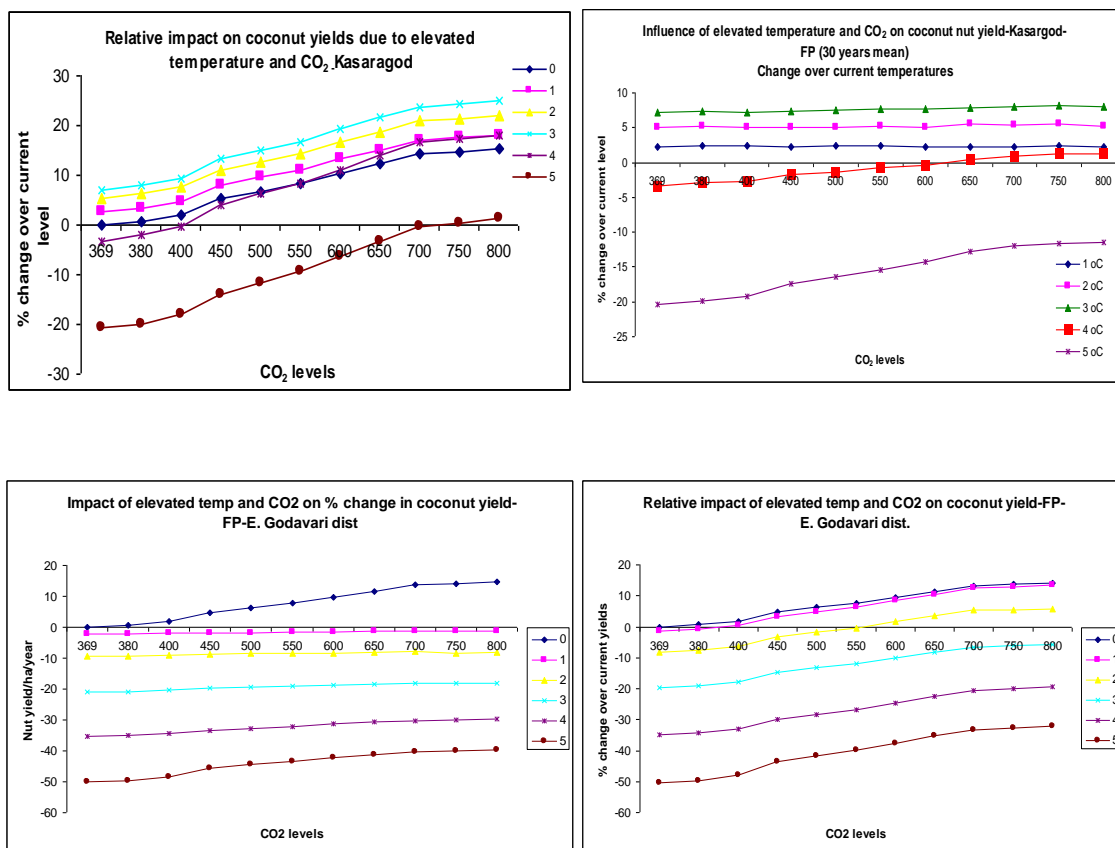
Fig 3: Influence of temperature on coconut daily crop growth rate in west coast represented by Kasaragod dist and east coast represented by Godavari dist.
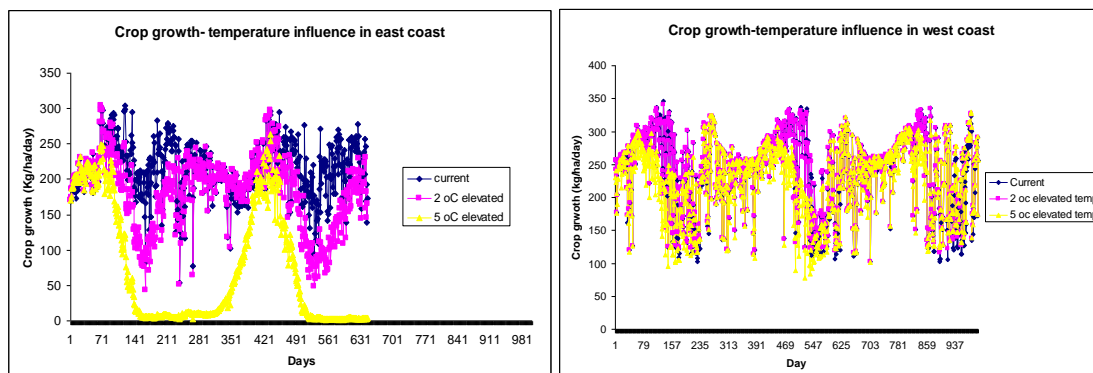
Using coconut simulation model, yields were simulated for 13 agro-climatic zones represented by 16 centres. These areas contribute over 90% to the coconut production in India. Simulations for yield projections were done for HadCM3 climate change storylines viz., A2a, B2a and A1F for 2020, 2050 and 2080 scenarios. The CO_2 projections of Bern CC model, temperature projections of HadCM3 model, location weather data for past 30 years, major soil type of the agro-climatic zone and currently followed farmer's practice for crop management in each agroclimatic zone (collected during surveys) are used as inputs into the coconut simulation model.

Fig 4: Methodology for simulating coconut yield projections in climate change scenarios
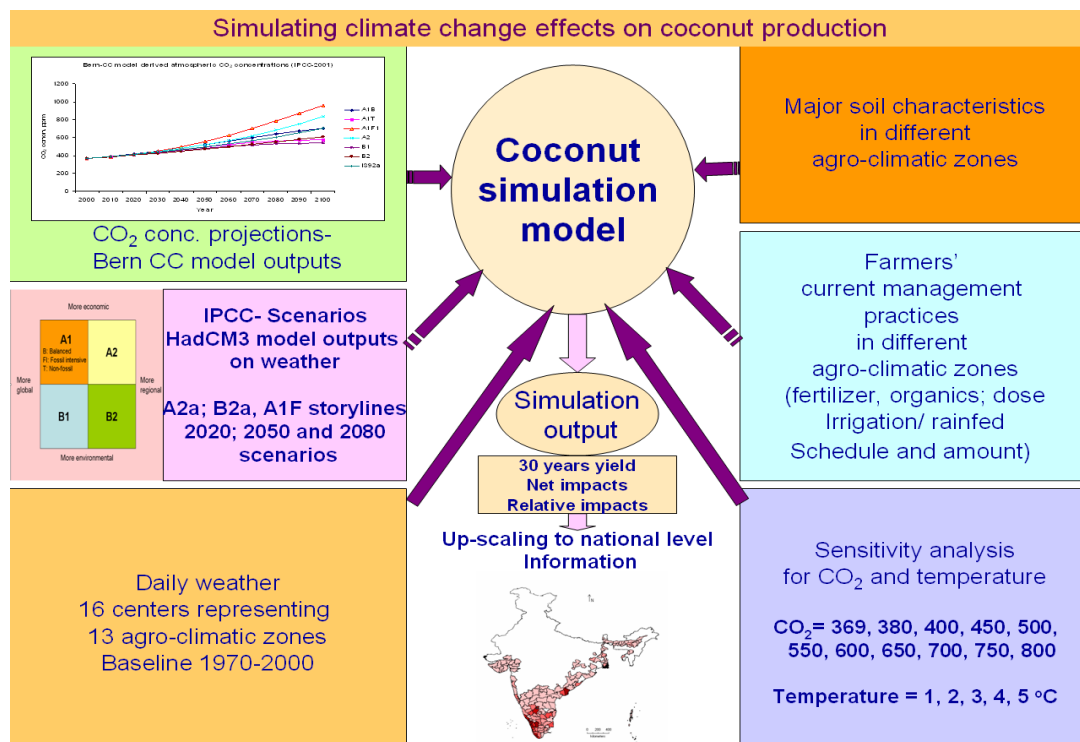
Relative impacts on yield were worked out at district level in a agro-climatic zones and up-scaled to state and national projections for impacts of climate change on coconut yield.

Results indicate that under all storylines, coconut productivity is projected to go up by up to 10% during 2020, up to 16% in 2050 and up to 36% in 2080 over current yields only due to climate change. However, in east coast yield is projected to decline by about 2% in 2020, 8% in 2050 and 31% in 2080 scenario over current yields due to climate change. Special variations exist. Yields are projected to go up in Kerala, Tamil Nadu, Karnataka, Maharastra while they are projected to decline in Andhra Pradesh, Orissa and Gujarat. It is also estimated based on the past 10 year domestic consumption trend that coconut consumption per capita may decline. However, projections show that demand for coconut may increase due to increase in population in the country. This brigs to the fore that

demand supply gap will increase in future even as coconut production is expected to rise due to climate change alone with existing management being practiced by the farmers. Thus to improve the productivity, more adoption of farming technologies by the farmers is essential, not only to bridge the supply demand gap but also to exploit the export opportunities.

COCONUT YIELD RELATIVE DEVIATION FROM CURRENT YIELD DUE TO CLIMATE CHANGE
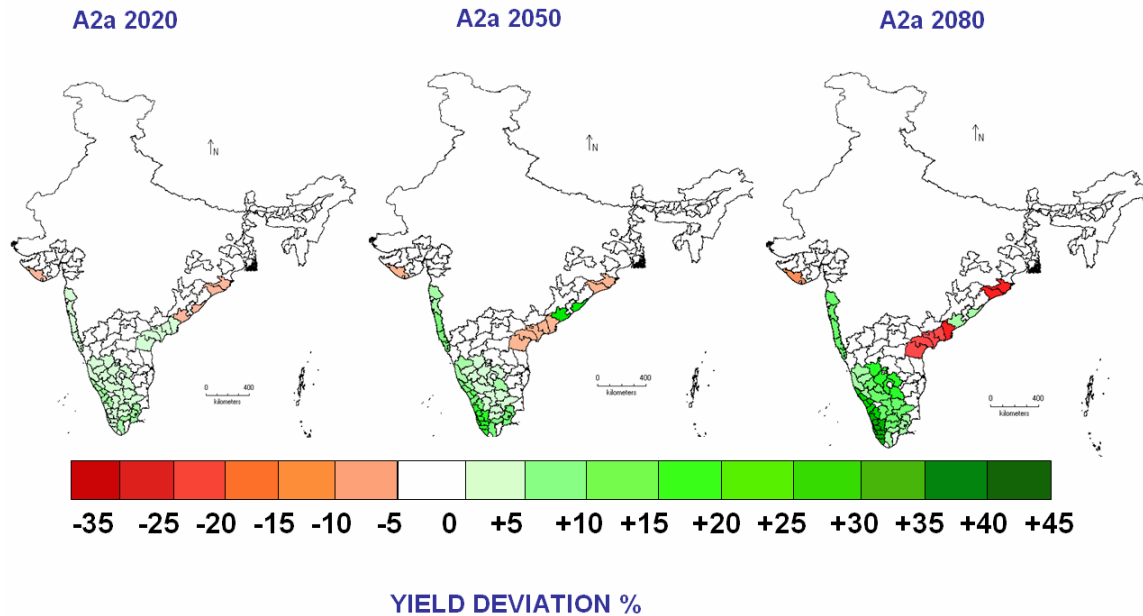
A2a 2020   **A2a 2050**   **A2a 2080**

-35 -25 -20 -15 -10 -5   0   +5 +10 +15 +20 +25 +30 +35 +40 +45

YIELD DEVIATION %

COCONUT YIELD RELATIVE DEVIATION FROM CURRENT YIELD DUE TO CLIMATE CHANGE

B2a 2020   **B2a 2050**   **B2a 2080**

-35 -25 -20 -15 -10 -5   0   +5 +10 +15 +20 +25 +30 +35 +40 +45

YIELD DEVIATION %

54

COCONUT YIELD RELATIVE DEVIATION FROM CURRENT YIELD DUE TO CLIMATE CHANGE

A1F 2020   A1F 2050   A1F 2080

YIELD DEVIATION %

-35 -25 -20 -15 -10 -5 0 +5 +10 +15 +20 +25 +30 +35 +40 +50
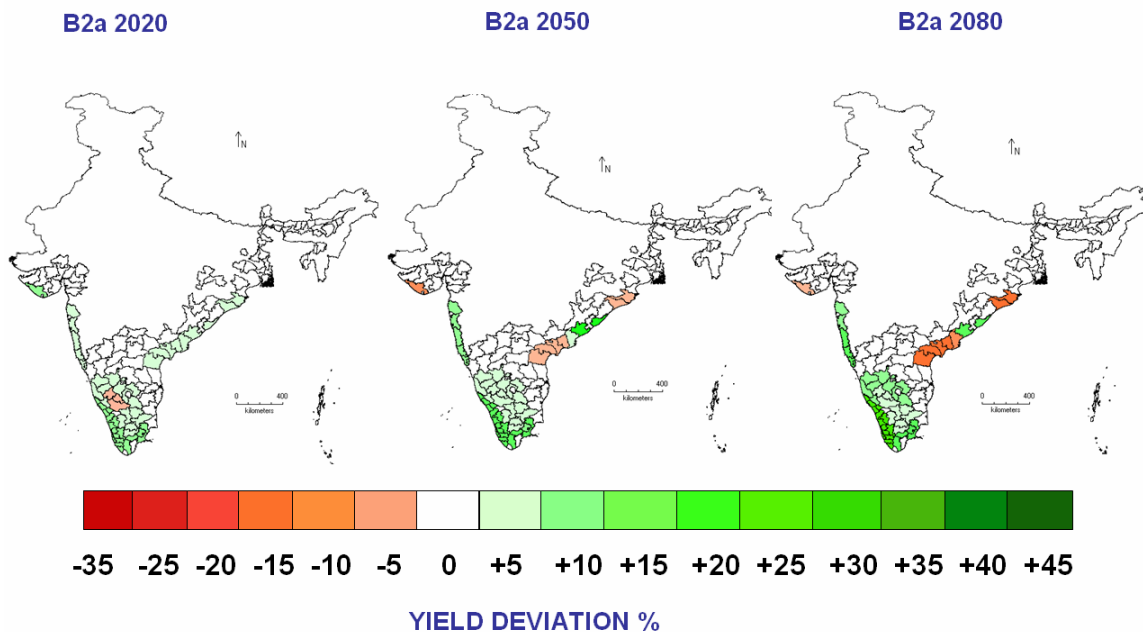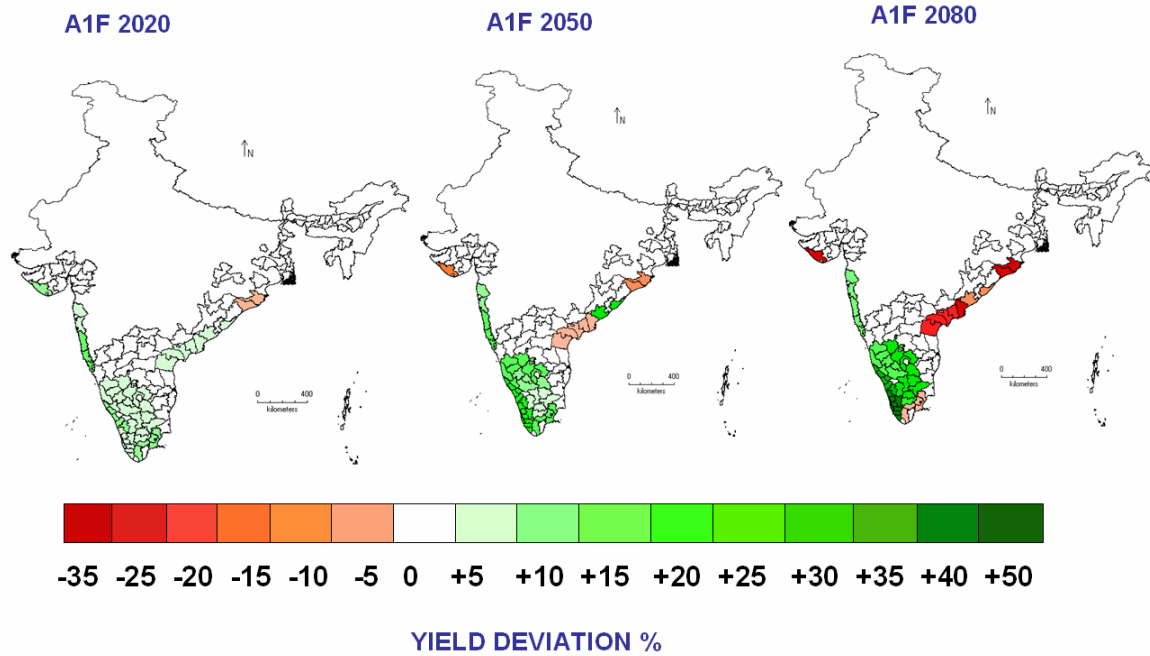
Fig 5. Projections on relative yield change in A2a, B2a and A1F scenarios

Coconut demand and yield projections in A2a storyline
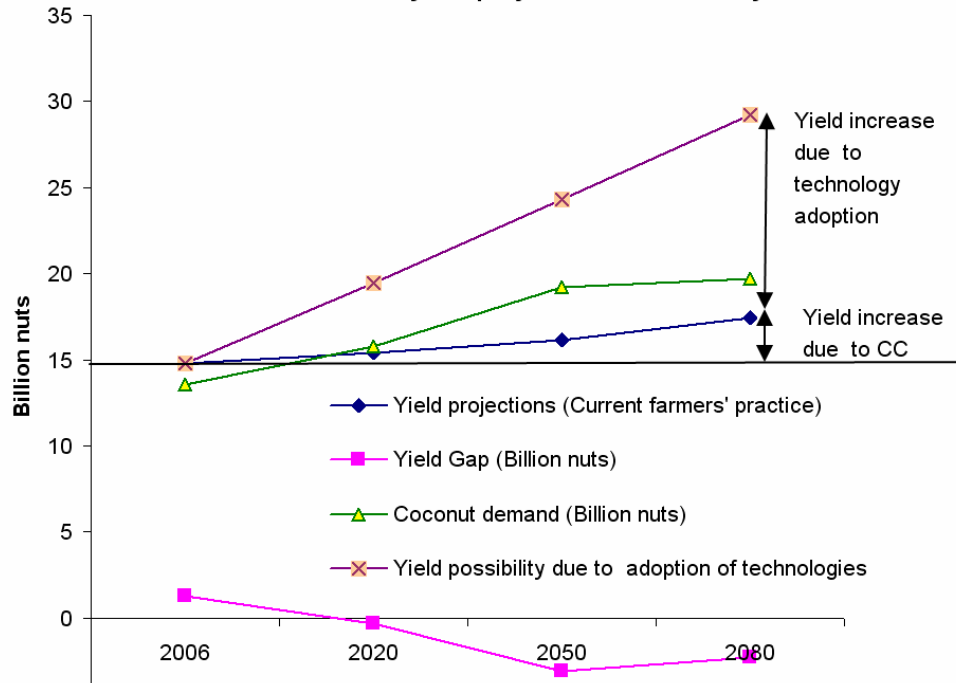
Coconut demand and yield projections in A2a storyline
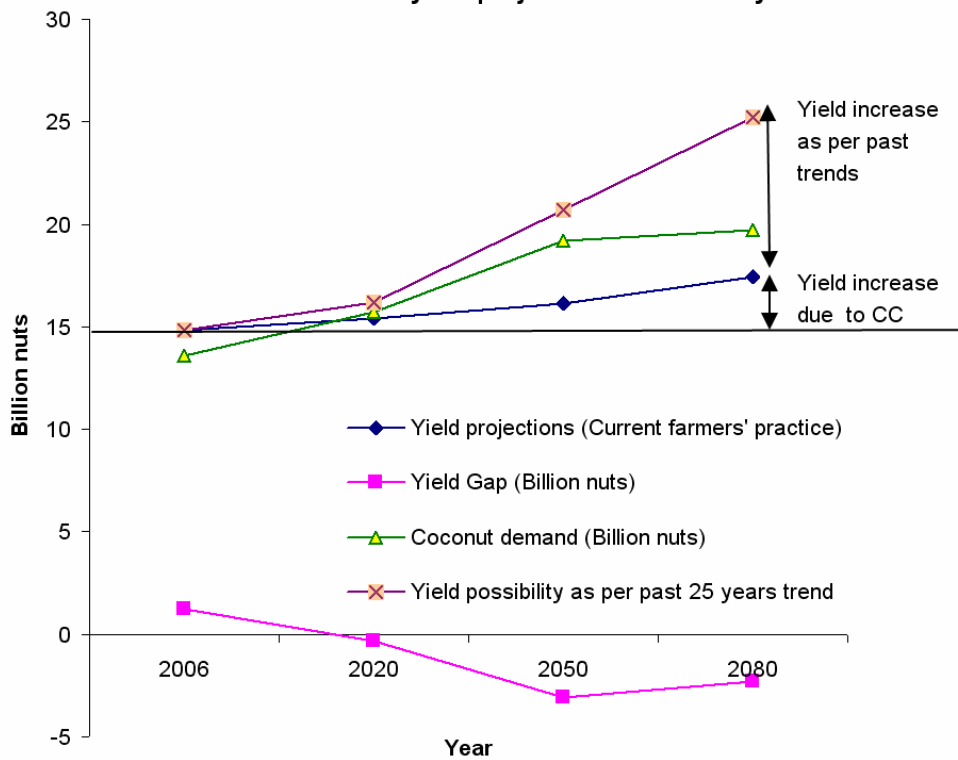
Fig 6. Demand and supply gap projection in coconut for future climate change scenarios

Demand-supply gap projections at current farmers' practice
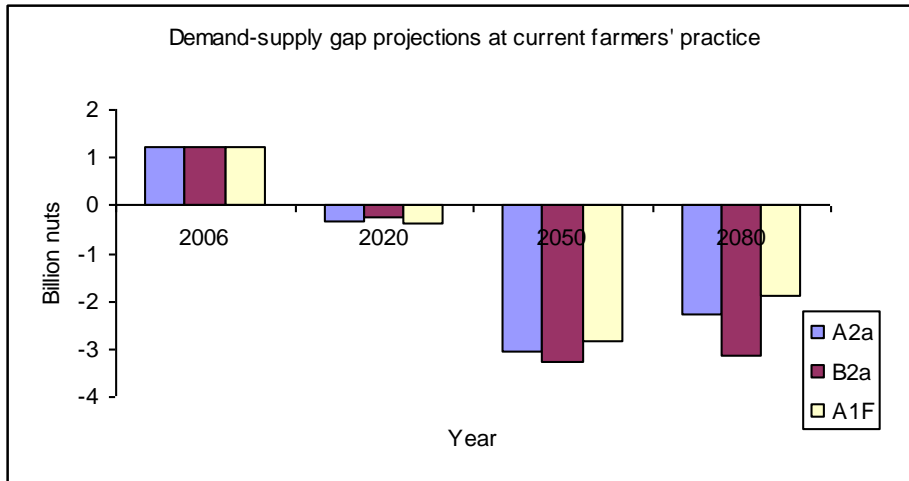
Objective 3: Study the suitability of measures of adaptation in coconut plantations to climate change in different agro-climatic zones using simulation model

Inputs given to coconut plantations in Kerala and parts of Karnataka are very merger and most of the plantations are rainfed. With the applications of any inputs like drip irrigation and recommended dose of fertilizers, etc, yields are expected to go up from current levels in these areas. In areas of Tamil Nadu and east coast of AP, most of the plantations are irrigated and well managed. Current yields in these areas are high and simulation studies indicated that the drip irrigation may further increase yields. A details analysis is yet to be done in this aspect. Our earlier studies indicated that soil moisture conservation strategies reduced the impact of dry spell and drought and helped the palms to produce higher yields. Survey conducted in drought affected areas also indicated that soil moisture conservation reduced the impact of drought on coconut palms. Adaptation of soil moisture conservation measures increased yield by 15%.

Objective 4: Study the effect of elevated temperature and CO_2 on growth of coconut seedlings.

In OTC experiments, morphological measurements, physiological and biochemical estimations were carried out on five cultivars (WCT, LCT, COD, COD x WCT and WCT x COD) under six OTCs and under shade net. The treatments include elevated CO_2 at 550 and 700ppm and elevated temperature at +3 ^{o}C over chamber control.

Fig 7. OTC facility at CPCRI, Kasaragod

Results on morphological and physiological parameters indicate that in general seedlings under shade net were healthy with high chlorophyll content, SLW, leaf area, shoot height, collar girth (after 12 months of growth), root and shoot dry matter and root volume as compared to those in OTCs. Only SLA was more in OTC seedlings. However, when comparison is made between seedlings grown under elevated CO_2 and temperature OTCs with those under chamber control, seedlings grown under elevated CO_2 had higher root dry matter, SLA, chlorophyll a/b ratio, collar girth, shoot height, shoot dry matter and leaf area. Seedlings exposed to elevated temperature has high shoot height, root length, collar girth and root dry matter and volume as compared to the chamber control. However, SLW was low in seedlings exposed to elevated temperature.

Fig 8. Morpho-physiological parameters in coconut seedlings under elevated CO₂ and temperature
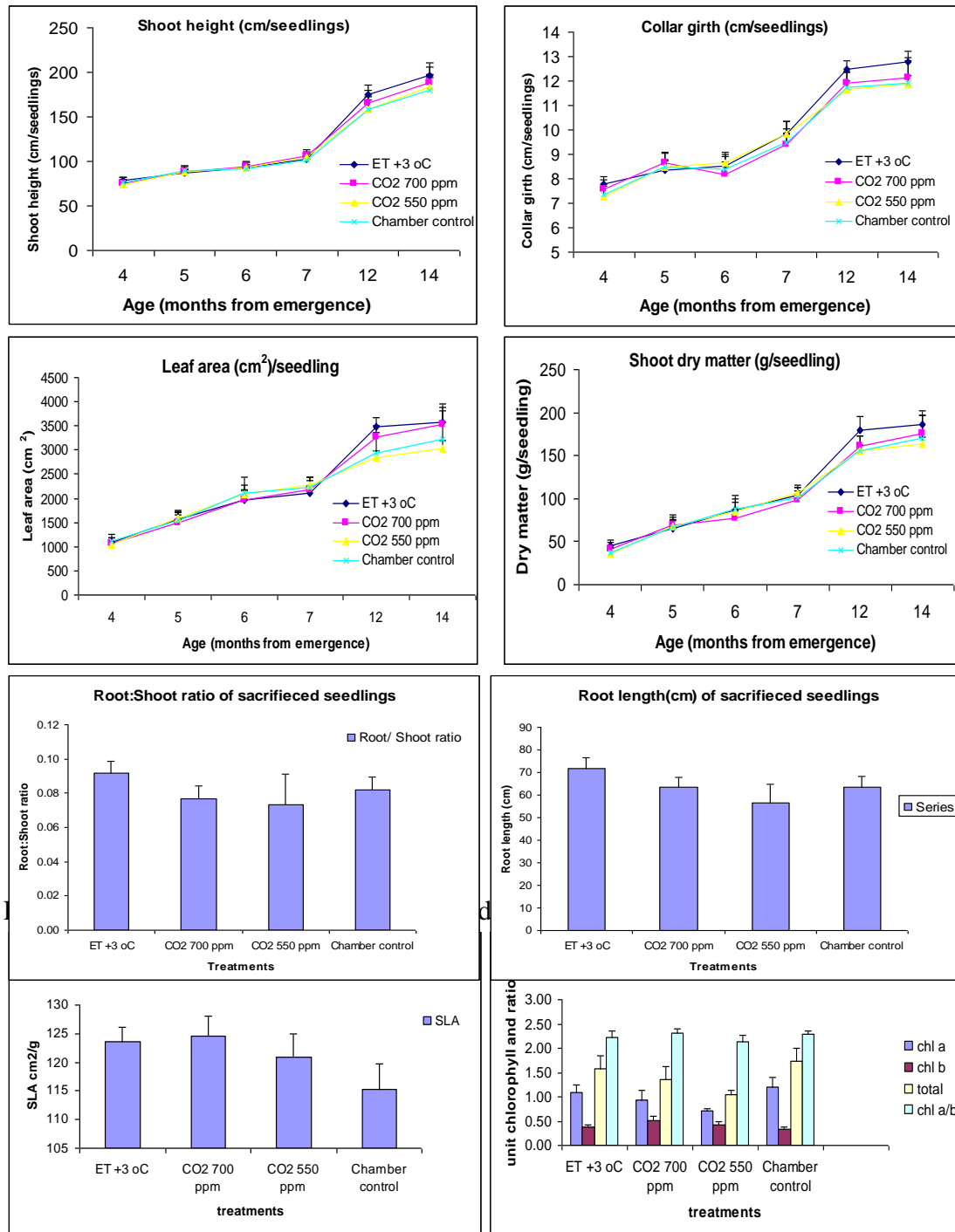
Fig 9: SLA and Chlorophyll content in seedlings under elevated CO₂ and temperature

Biochemical parameters analyzed were total soluble sugars, reducing sugars, starch, non-reducing sugars, total phenol, free amino acids, proteins and heat stable protein fraction in leaf tissue.
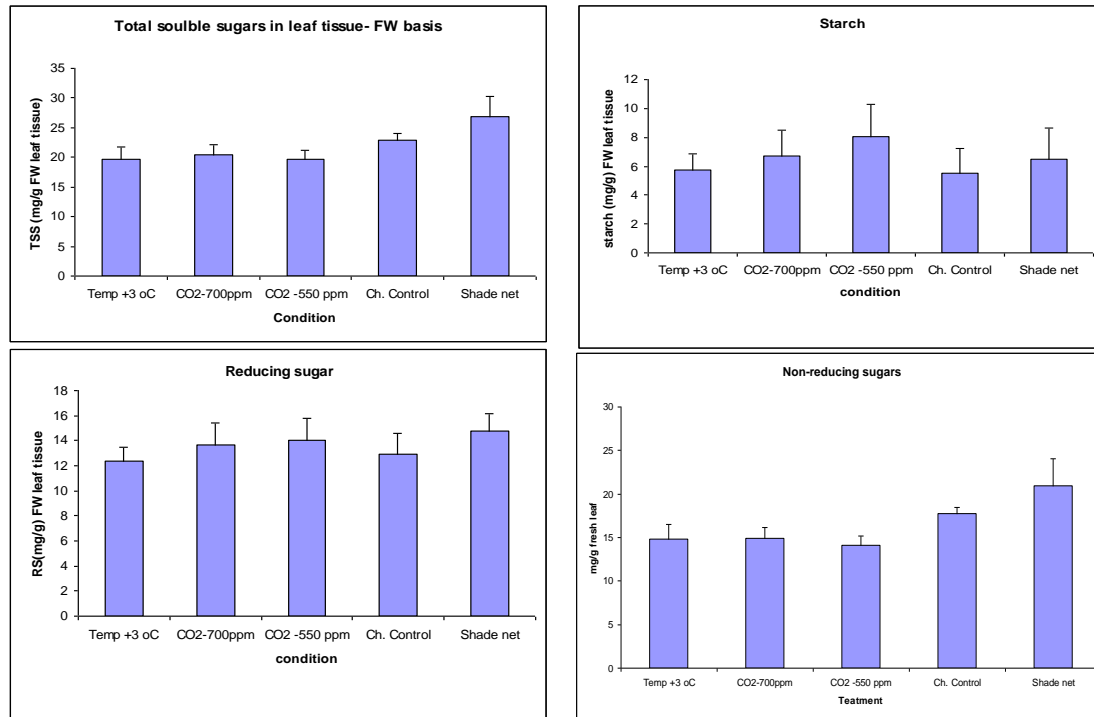
Fig 10. Biochemical parameters in seedlings under elevated CO_2 and temperature

The results indicated that biochemical parameters such as total soluble sugars, total phenols and reducing sugars had higher values under shade net condition as compared to that of seedlings in open top chambers. On the other hand free amino acids were higher in seedlings maintained in OTCs. Among the treatments, when compared to the chamber control, free amino acids were more in seedlings grown under elevated CO_2 levels of 700ppm followed by those grown under 550ppm CO_2 levels. Total phenol content, which interestingly reduced under open top chamber conditions, was more seedlings exposed to elevated temperature treatment as compared to that in chamber control. Starch and reducing sugars were higher in seedlings grown in elevated CO_2 condition as compared to the chamber control seedlings.
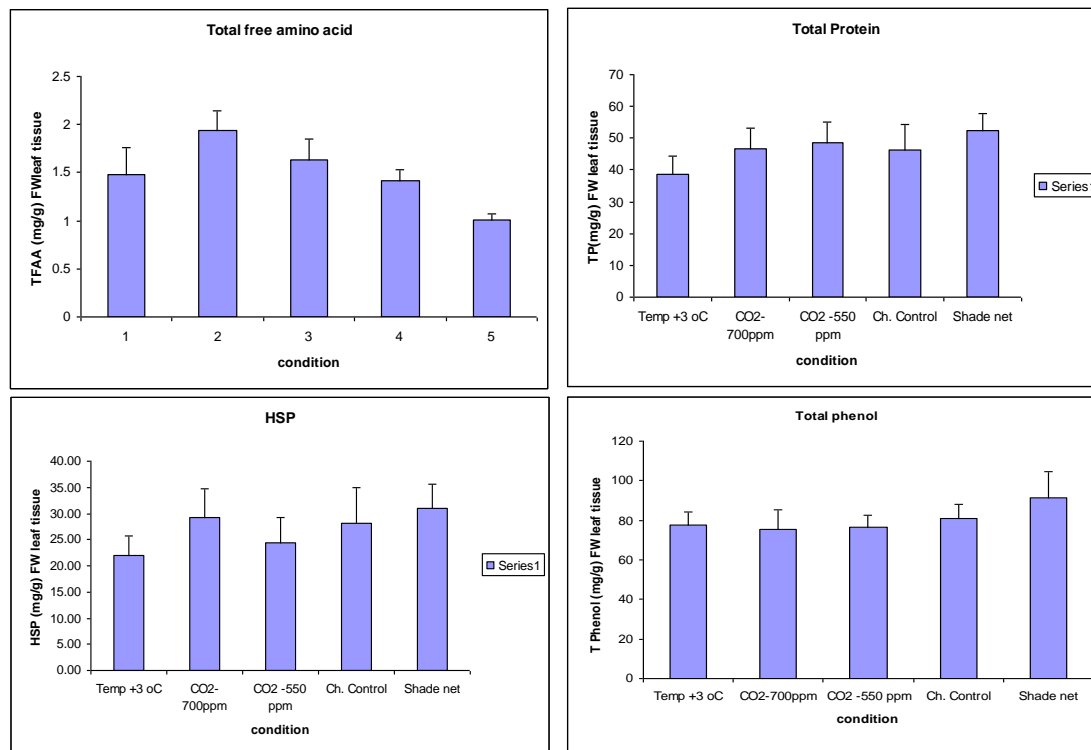
Fig 11. Biochemical parameters in seedlings under elevated CO_2 and temperature

Sap-flow estimations were carried out during year on adult palms. Data is related to the weather parameters. Sap flow analysis indicated that sapflow in coconut is closely related to the VPD and sun shine.
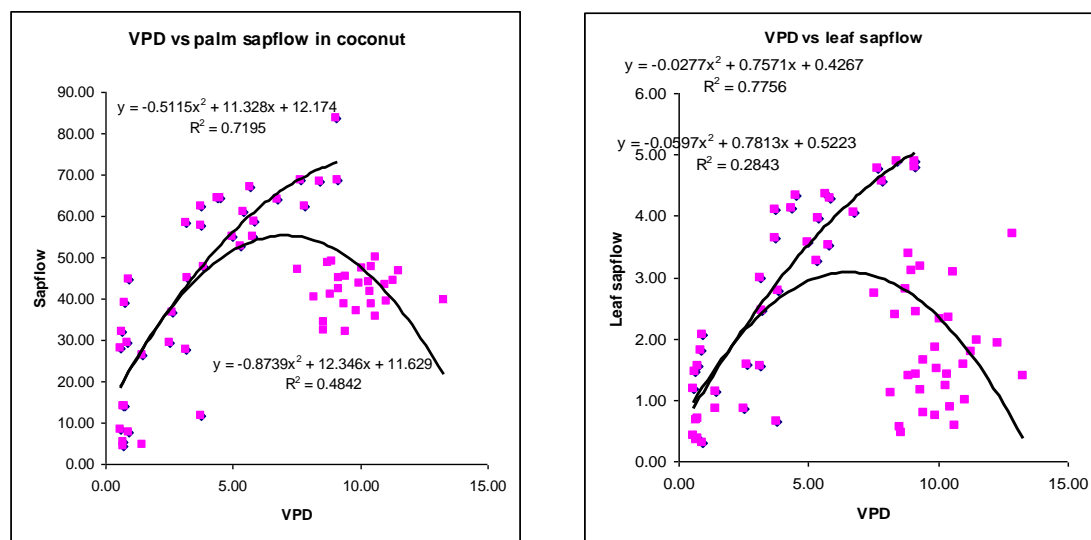
Fig 12. Sapflow in coconut in relation to vapour pressure deficit

Objective 5. Study the carbon sequestration potential and stocks of coconut mono-systems using simulation model.

Estimations on carbon sequestration potential and stock in coconut plantations under different management conditions and agro-climatic zones were continued. The net primary production (NPP) estimations of coconut monocrop in different agro-climatic zones indicated annual carbon sequestration potential of coconut above ground biomass ranged from 8 to 32 t CO_2/ha/year depending on cultivar, agro-climatic zone, soil type and management. Further work on estimations for entire life cycle of coconut using coconut simulation model and up-scaling to national potentials are under progress.

Central Research Institute for Dryland Agriculture, Hyderabad

The state of Andhra Pradesh is divided into seven agro-climatic zones by NARP project and recently two more agro-climatic zones are added by bifurcating Krishna-Godavari zone and North Telangana zone.

The state is endowed with a variety of soils ranging from poor coastal sands to highly fertile deltaic alluviums. Red soils occupy over 66%, Black soils cover nearly 25%. The alluvial loamy clay soils cover 5%. The coastal sands occupy only 3% while the remaining 1% is covered by laterites soils of the cultivated area in the states. The states receive rainfall from both SW and NE monsoon. However there is a regional variability in the spatial and temporal distribution of rainfall. Thermal environment of the state is suitable to grow variety crops like paddy, sugarcane, groundnut, sorghum, maize, pulses, millets, red gram, cotton and caster etc.

Data Collection

Daily weather data from different weather stations (IMD) in different agroclimatic zones of Andhra Pradesh was collected, compiled. District wise, crop wise area, production and productivity data was also collected from CMIE database. Crop wise variety, date of sowing and fertilizer input information was collected from the 'Vyvasaya Panchangam' published by ANGRAU, Hyderabad. Soils information was collected from different sources like NBSS&LUP, ANGRAUetc.

Climate trends
Rainfall

The rainfall data of 174 stations well spread over Andhra Pradesh with a period ranging from 1871 to 2004 years was analysed and the significant trends were identified using the Mann Kendall test of significance. Using these values a rainfall trend map of Andhra Pradesh (Fig.1.) was generated. Decreasing trend significant at 1% level was showed in some areas in Guntur, Nalgonda, Warangal, khammam, parts of Adilabad and Mahaboobnagar districts. Whereas, some parts of districts Chittoor, Nellore Kadapa, Prakasam, Guntur, Adilabad, Khammam and Srikakulam showed increasing trend (significant at 1% level) for annual ranfall.
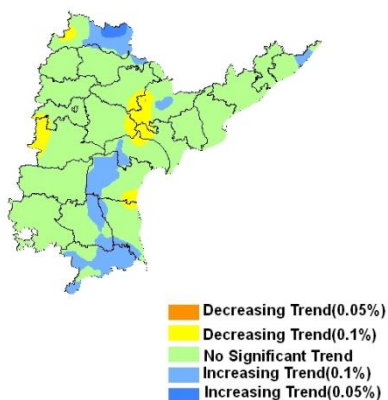
Fig.1. Rainfall trends over Andhra Pradesh

Decadal Shifts in Monthly rainfall (Kharif season)

Monthly rainfall for the period of 30 years (1971-2007) from 23 stations representing seven agro-climatic zone of Andhra Pradesh was analysed. In Andhra Pradesh major crop growing season *Kharif* starting from June and it is extending up to October as some parts of south Andhra (Rayalaseema) is getting rainfall during northeast monsoon (October-December) also.

There is an increased rainfall activity in all the months except in August in Krishna-Godavari zone (Fig 2.). This is a cause of concern as the decrease in rainfall during August may affect important stage anthesis and flowering of paddy, major crop of this zone. On the other hand, the rainfall increase in the month of September and October disturb the harvesting and post-harvesting operations. In North Coastal zone increasing tendency in rainfall was seen in the months of June and October and remaining months showed slight increase in rainfall in some stations.

In the case of Southern zone, June, July and October months showed upward trend in rainfall and downward trend during August and September. First two months of kharif season showed decreasing rainfall tendency in North Telangana zone. Perhaps this may create problem for better establishment of crops and their subsequent growth. In the other three months there was no such trend seen in most of stations.

In Southern Telangana zone decreasing trend in rainfall in June, July and August while increasing trend during September and October months was seen. In Scarce Rainfall zone increasing trend was seen during all months except in August during which there was no change in rainfall pattern, which may brighten the prospects of good harvest.

In the case of High Altitude zone, June to October month's rainfall was showing increasing tendency especially during the current decade (2001-2007).

Decadal Changes in drought Pattern

Annual drought intensity was calculated for the period of 30 years (1971-2000) for 23 stations based on the criteria of National Commission on Agriculture (1976) for drought category. The frequency of occurrence of various intensities of drought have been computed and the percent probabilities during different decades which worked out (Table 1).

Table.1 Change in percentage of occurrence of droughts in different agro-climatic zones of Andhra Pradesh

Agro-climatic zone	1971-1980	1981-1990	1991-2000
Krishna-Godavari Zone	62.5	47.5	57.5
North Coastal Zone	63.3	50.0	60.0
Southern Zone	50.0	63.3	43.3
North Telangana zone	75.0	35.0	60.0
South Telangana Zone	55.0	47.5	62.5
Scarce Rainfall zone	60.0	56.6	46.6
High Altitude Zone	50.0	60.0	60.0

Fig.2. Rainfall shifts in Andhra Pradesh
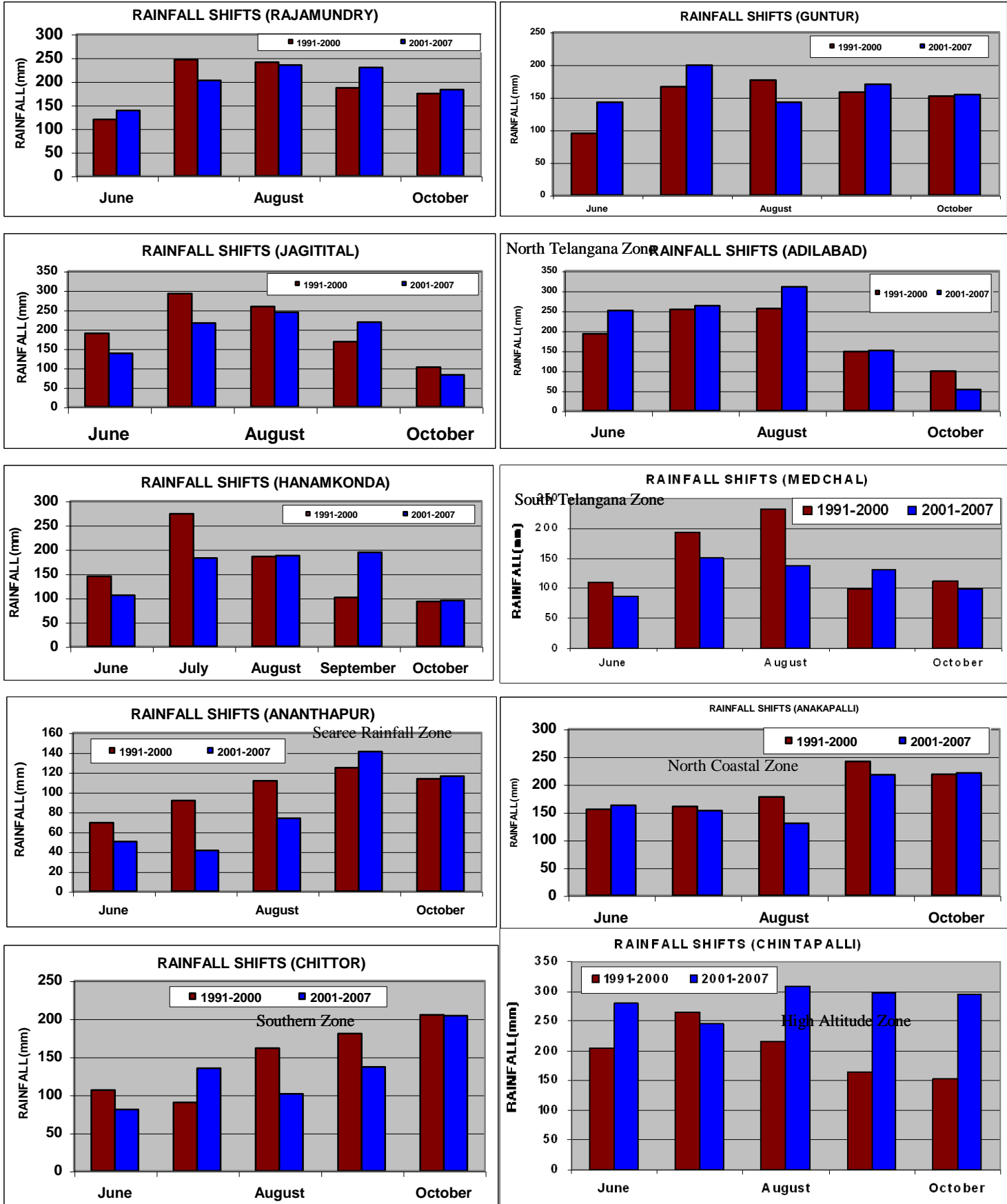
The results revealed that the highest (75%) and lowest (35%) percentage of occurrence of drought was noticed in North Telangana zone during the decade of 1971-1980 and 1981-1990, respectively. The percentage of occurrence of droughts were more during 1971-1980 and 1991-2000 decades when compared to 1981-1990 decade in all agro-climatic zones except Southern and Scarce rainfall zones (Table.1). In these two zones percentage of drought were more in 1971-1980 and 1981-0990 decade than recent decade 1991-2000.

Temperature trends:
Temperature (maximum, minimum and average) data of 30 years were analysed for different locations in Andhra Pradesh. The results revealed that the temperatures had shown considerable increase in day, night and also average annual temperatures. But at Khammam, the day time temperatures had shown considerable decreasing trend where as night temperatures showed an increasing trend. Overall the average annual temperature has shown a decreasing trend. Whereas at Visakhapatnam daytime temperatures have shown increasing and while night time temperatures showed decreasing trend, overall the average annual temperature showed an increasing temperature at many locations in the state.

Effect of rainfall and temperature on crop yields:
The yields of various crops like rice, sorghum, groundnut, etc. versus rainfall and temperature trends were analysed for all the districts. A few significant relationships are given below. The relationship between rainfall and sorghum production at Anantapur showed a negative relationship with rainfall in most of the years which may be attributed to uneven distribution of rainfall during the crop growth period. In case of temperature whenever the seasonal average temperature increases production reduced. The paddy production in Visakhapatnam had direct relationship with rainfall during most of the years, whereas average annual temperature had indirect relationship with the paddy production. There was direct relationship between rainfall and production of sorghum in Ranga Reddy. At Mahaboobnagar also the sorghum production has direct relationship with rainfall. Though there was negative relationship between temperature and production. Positive relationship was found between groundnut production and rainfall at Kurnool in most of years. There was clear-cut negative relationship between temperature and groundnut production. At Warangal rainfall during the crop growth period positively influenced the paddy production. There was not much variation in temperature at Warangal and it was found that the production was not affected either positively or negatively by temperature. There was an indirect relationship between paddy production and rainfall at Khammam at the same time positive relationship was seen between temperature and paddy production.

Validation of InfoCrop model output:
Validation of InfoCrop model for rainfed crops viz., sorghum, pearlmillet, maize, cotton and redgram at different stations located in 7 agroclimatic zones of Andhra Pradesh were carried out. Station-wise weather data of Anantapur, Karimnagar (Jagityal) and Rangareddy was used in the InfoCrop programme after converting them into model format. The district-wise observed yield data for the same period was collected. After the

simulation, the yields of simulated and observed were compared. The root mean square error values were very high in the case of maize, cotton and redgram. The simulated yields of sorghum and millet have shown a close relationship with the observed yields as the root mean square error values were smaller.

Anantapur - Sorghum
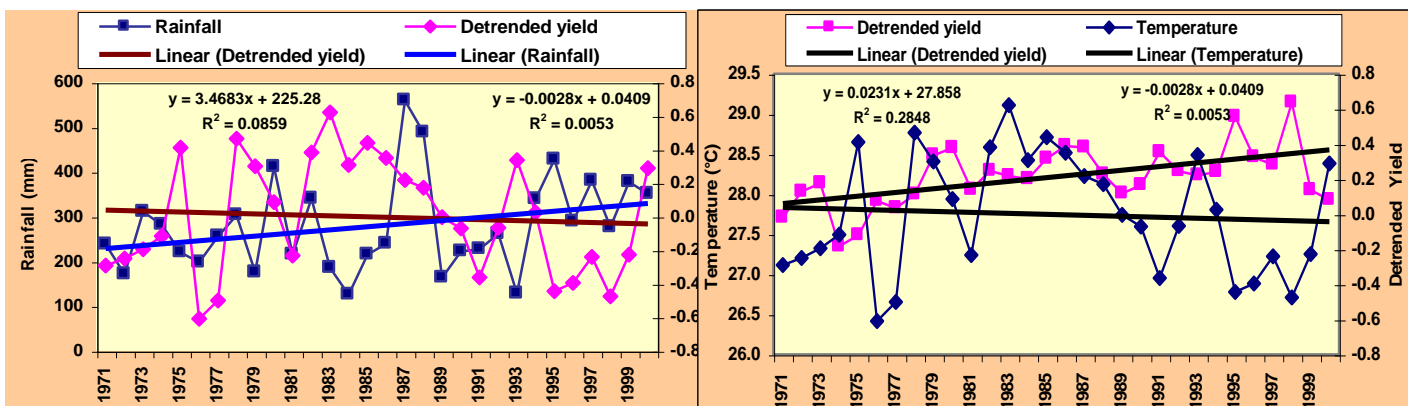
Vishakapatnam - Paddy
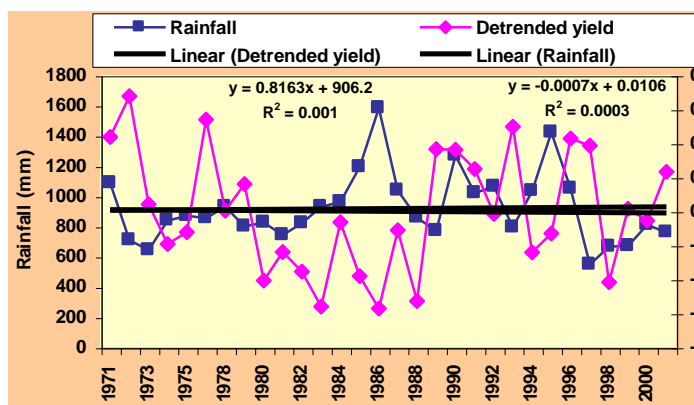
Ranga Reddy - Sorghum
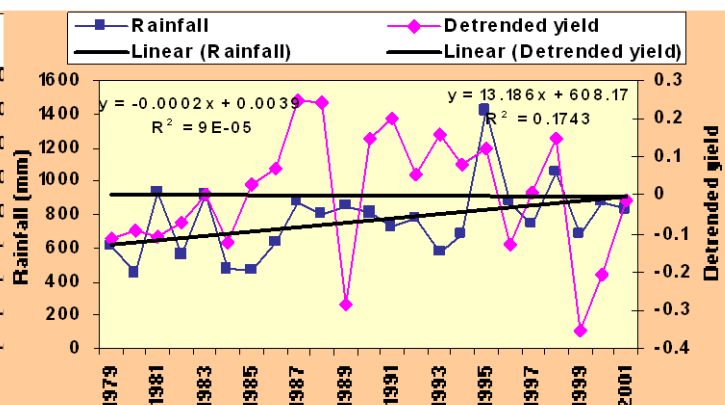
Mahabubnagar - Sorghum
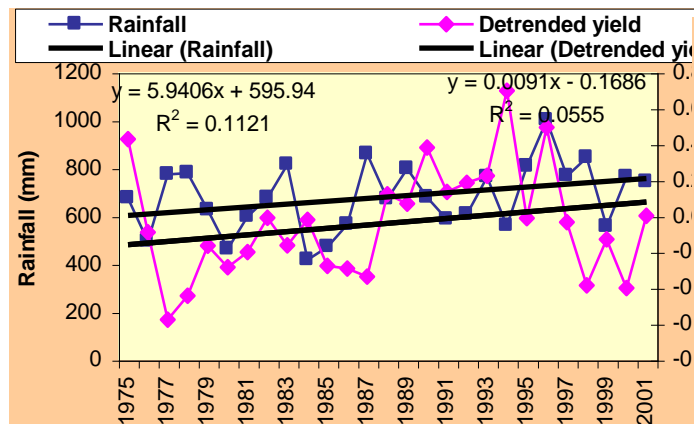
Kurnool - Sorghum
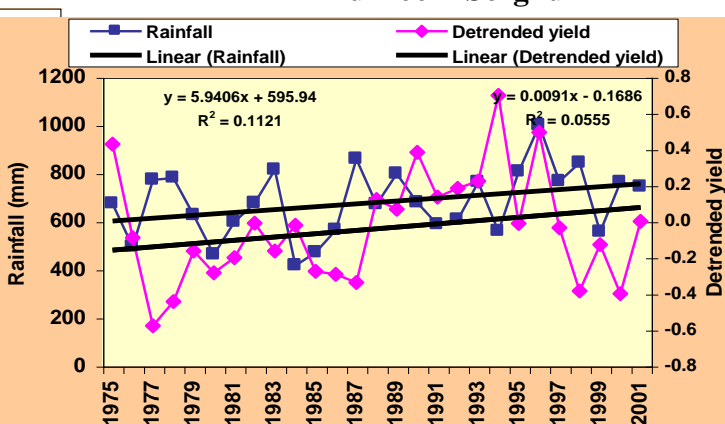
Warangal - Paddy
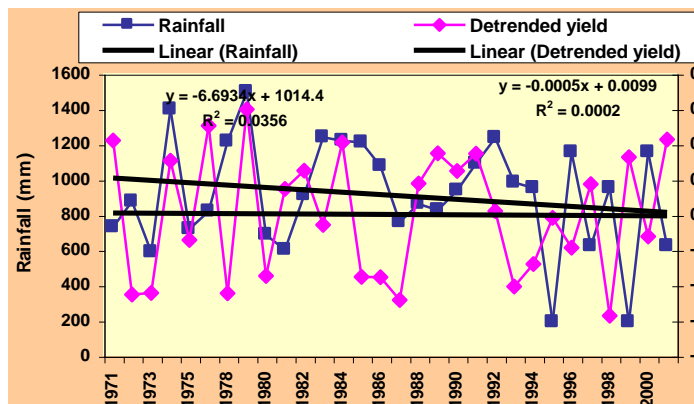
Khammam - Paddy
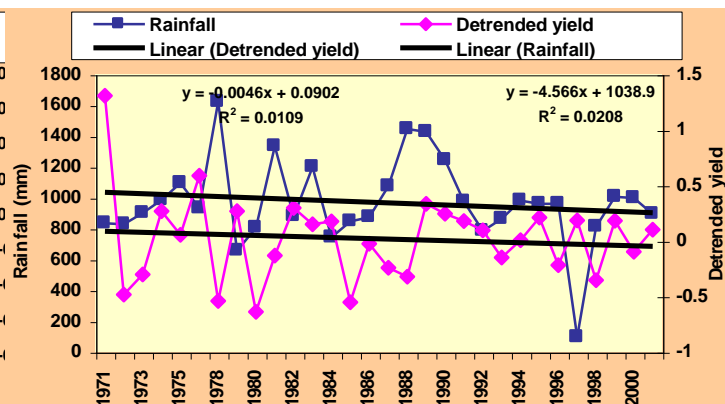
Impact of elevated CO$_2$ and temperature on insect-plant interactions

The following activities were undertaken during the project period.

1. Experiments on impact of elevated CO$_2$ on insect pets
2. Determination of thermal requirements of *H. armigera*
3. Estimation of crop loss ratios using wet weeks approach
4. Estimation of yield losses of castor due to pests using secondary data.

Experiments on impact of elevated CO$_2$ on insect pets
Feeding trials using neonate larvae were performed five replicates for all four treatments. Ten larvae were placed in separate petridishes for each replication with one leaf portion inserted in moistened filter paper to maintain leaf turgidity. Lateral leaves from matched plants were used to determine the dry weight and nutritional quality of the offered leaves. The initial area and weight of the leaves offered to the larvae at the start of the feeding and the leaf material remaining at the end of feeding trial (every 24 hr) were measured. The initial and final fresh weights of the larvae and their faecal matter were also measured. At the end of feeding period, larvae were weighed and remaining foliage and frass were dried at 40°C.

Consumption pattern of *S. litura* on castor
In case of *S.litura* the total consumption of castor foliage during entire feeding period was significantly more under elevated CO$_2$ conditions (0.820±0.131 and 0.869±0.054 gm leaf dry weight) than other ambient and chamber treatments (0.594±0.044 and 0.588±0.192 gm) indicating that about 39% more consumption under elevated CO$_2$ conditions (Table.1). Final larval dry weights differed significantly among treatments and the impact of elevated CO$_2$ on larval weight of *S.litura* on castor. The larval weights were also more (0.137±0.002 and 0.137± 0.011gm) when larvae were allowed to feed on foliage obtained from castor grown under elevated CO$_2$ condition than the rest of the conditions (0.117±0.006 and 0.118 ±0.002gm). The larval developmental time (time from first larval instar until pupation) differed significantly among CO$_2$ conditions. Larvae fed with castor foliage grown under elevated CO$_2$ conditions developed slower than those on plants grown at ambient conditions.

Indices of insect performance
S.litura indices varied significantly among treatments (Table2). Approximate digestibility of larvae was higher in elevated CO$_2$ conditions (70.61±3.99 and 74.66±2.96) than in ambient and chamber treatments indicating that CO$_2$ foliage was about 13% more digestible than ambient CO$_2$ foliage. RCR of larvae was more when allowed to feed on foliage obtained from elevated CO$_2$ conditions than corresponding rest of treatments. The values of ECD were higher in ambient (35.46±3.799%) and chamber treatments (33.59±5.62%) indicating a decrease by 10% in larvae fed on foliage grown in high CO$_2$ conditions (21.22±4.07 and 23.71±5.53%). The relative growth rates (RGR) of insect was non significantly influenced by elevated CO$_2$.

Table 2.Impact of elevated CO$_2$ on *Spodoptera litura* on castor

Treatments	Weight of leaf ingested (g)	Larval weight(g)	AD %	ECI %	ECD %	RCR mg.mg^{-1}.d^{-1}	RGR mg.mg^{-1}.d^{-1}
Elevated CO$_2$ 550 ppm	0.820±0.131	0.137±0.002	70.61±3.99	16.74 ±2.88	23.71± 5.53	45.57± 7.32	76.31±0.159
Elevated CO$_2$ 700 ppm	0.869±0.054	0.137±0.001	74.66±2.96	15.83 ±2.32	21.22± 4.07	48.27± 3.01	76.45±0.611
Ambient CO$_2$ - Chamber	0.594±0.044	0.117±0.006	58.80±4.01	19.75 ±1.83	33.59± 5.62	37.12±2.79	73.33±0.344
Ambient CO$_2$ - Open	0.588±0.192	0.118±0.002	57.02±7.23	20.20 ±0.95	35.46± 3.79	36.74±0.19	74.25±0.152
SEm±	0.048	0.0003	0.031	1.210	3.01	2.81	3.12
LSD (p=0.05%)	0.166	0.011	0.106	NS	10.51	9.621	NS
CV%	11.59	4.70	8.13	11.65	10.23	11.24	5.19

Determination of thermal requirements

The thermal requirements (degree days) of development are often used for estimating the developmental times because temperature has a major effect in determining the rate at which insect develops. The effects of constant temperatures (15-30°C) on the rate of development of life stages of *H.armigera* reared on artificial diet were investigated. Development of *H.armigera* tends to be faster on artificial diet than on most host plants. Another source of developmental variation in *H.armigera* is variation in host plants used as a food, either in terms of defensive chemistry or nutrition value. The dilution of nutritional value of host plants grown in elevated CO_2 was observed and developmental variation was also observed due to the dilution in host plants. This was considered as a hypothesis to estimate the variation of thermal requirements of insect pests. During the present year the thermal requirements were estimated.

The thermal requirements for *H.armigera* on artificial diet and cotton leaf obtained from elevated CO_2 conditions were estimated. The degree-days requirement of *H.armigera* on artificial diet at three levels of CO_2 condition was given in the Table 3. No variation was observed in degree-days for larvae when reared on artificial diet across three CO_2 concentrations. However, degree-days requirement of *H.armigera* larvae increased when reared on cotton leaf obtained from elevated CO_2 concentrations than leaf obtained from ambient conditions.

Table 3.Impact of elevated CO_2 on degree days of *H.armigera*

Treatments	CO_2 Concentrations					
	Ambient		Elevated			
	365ppm		550ppm		700ppm	
	Days	DD	Days	DD	Days	DD
Artificial Diet	24.38	210.50	24.58	212.55	24.75	215.37
Cotton leaf	24.30	210.13	25.05	217.95	25.33	221.30

Estimation of crop loss ratios-wet weeks

Determination of probabilities of wet & dry weeks during crop growing season for Ranagreddy district of AP.

During the year development of risk management options using cost loss estimates for Sorghum was taken up

The weather data on was analyzed using "Markov chain model" in FORTRAN language to determine wet and dry weeks. Shoot fly (*Atherigona socata* Rond.) is a widespread and damaging pest in all the sorghum-growing areas in semi arid tropics. As a result of larvae feeding, the central leaf wilts and later dries up giving the typical dead heart symptom. The loss in yield was reported to be about 90-100 percent. The occurrence of wet week (p+0.21-0.42) during 30 days from sowing promotes the incidence of this pest. This can be controlled by using systematic insecticide like carbofuran (12-13kgha^{-1}). The probability of occurrence of wet week in this case also is greater than cost-loss ratio (C/L). Hence protective action would be beneficial. The expected expense if protective action is taken on the basis of climatalogical probability of wet week is Rs. 600 ha^{-1}. The equivalent cost on the basis of perfect forecast of wet week reduces to Rs. 126-252 ha^{-1} (Table 4.)

Table 4.Cost-loss ratios, appropriate strategies for pest control in Sorghum

Pests/Diseases	Adverse weather event and critical period	Probabilities of wet week (P_W)	Cost (Rs./ha)	Loss (Rs./ha)	C/L	Strategy	Eo (Rs.ha-1)	E* (Rs.ha-1)
Sugary disease	Wet spell Anthesis stage	0.46	800	5,000 8,000	0.160.10	Adopt	800	368
Grain mold	Wet spell Grain formation stage	0.33 0.75	850	5,000	0.17	Adopt	850	280.5 637.5
Shoot fly	Wet spell Within one month from sowing	0.21 0.53	600	9,000	0.07	Adopt	600	126 318
Stem borer	Wet spell 4th week to harvest	0.21 0.75	600	5,500 8,500	0.11 0.07	Adopt	600	126 450

Eo= Equivalent cost, if the strategy is chosen on the basis of climatalogical probabilities information alone
E*= Equivalent cost for a strategy based on perfect forecast

4. Estimation of yield losses in castor crop

Yield infestation relation ships in castor were worked out using secondary data. It is estimated that 1% of damage by castor semilooper causes 15.33 kg loss of yield per hectare. And 1 larva per plant causes 51.99 kgs yield loss per hectare

Impact of Elevated CO_2 on Important Rainfed Crops-Castor and Groundnut

Objectives
1. To study the growth and yield of groundnut under elevated CO_2 and moisture stress
2. To study the impact of enhanced CO_2 levels on seed quality

Materials and Methods
The groundnut (*Arachis hypogaea*) cv JL-24 crop was raised in open top chambers (OTCs) to study the effect of different levels of CO_2 (700, 550 and 365 ppm) on growth and yield. Two individual chambers were maintained for each CO_2 levels as replicates. The chambers without any external CO_2 supply served as ambient chamber control (Ch-control). The elevated CO_2 concentrations were maintained throughout the growth period and monitored continuously during experimental period.
The groundnut crop was raised during Rabi and Kharif. The Rabi crop was raised under irrigated conditions. In order to quantify the interaction of elevated CO_2 and moisture stress, irrigation was with held for 10 days at 30 days after sowing (DAS) until visual symptoms of moisture stress appeared in one set of chambers and later the stress was relieved. The impact of moisture stress and its interaction with elevated CO_2 was quantified at harvest in terms of total biomass as well as pod yield.
During Kharif, the groundnut crop was raised as rainfed in OTCs. The crop received well-distributed rainfall of 259.4 mm in 19 rainy days and without any prolonged dry spells during crop growth period. The crop was maintained up to 105 days and for biomass studies, sampling was done at different time intervals (10, 20, 30, 45, 60, 75, 90 and 105 DAS) in order to quantify the response of CO_2 at different growth stages. For each treatment, three plants were sampled in two replications from each chamber. At harvest the total biomass, pod yield and yield components viz., number of pods, pod dry weight (g/plant), seed yield (g/plant) and 100 seed weight (g) were recorded. Total oil content was determined in seeds by using Soxhlet apparatus.

Results

Groundnut crop grown in rabi season, responded positively to increased CO_2 levels in terms of biomass and pod yield as compared with ambient level chamber control. The response of groundnut was significantly evident at 700ppm. The increased CO_2 level (700ppm) improved total biomass (10.9%) and pod weight (11.7%) at harvest.
The moisture stress at 30 DAS improved the biomass under chamber conditions with both elevated and ambient CO_2 conditions. The increment in biomass (23.6%) and pod weight (17.4%) under elevated CO_2 (700ppm) in combination of moisture stress was found to be better than in irrigated condition (Table 5). The improvement in total biomass was found to be higher than increase in pod weight with moisture stress and elevated CO_2

levels. This resulted reduced harvest index under moisture stress as compared with irrigated conditions.

Table-5: Seed yield of groundnut under different levels of elevated CO_2 (700, 550ppm), ambient chamber control and open control-Rabi

| Parameters | Conditions | | | | | | | |
| | 700ppm | | 550ppm | | Ch-Control | | Open Control | |
	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress	Irrigated	Stress
Total plant biomass (g/pl)	23.1	27.7	18.5	23.8	20.8	25.3	45.1	44.8
No. of pods	10	11	12	11	11	13	26	31
Pod dry wt. (g/pl)	10.3	12.3	10.5	10.4	9.2	10.4	19.6	19.4
Seed wt. (g/pl)	6.6	7.7	5.7	7.3	6.8	8.9	13.8	11.7
100 Seed wt. (g/pl)	43.8	37.1	41.5	38.6	42.2	46.3	41.7	27.0
HI %	28.7	27.9	31.1	30.8	32.8	35.4	30.5	26.1

The different components of groundnut plant responded differently with moisture stress and CO_2 levels (Fig. 4). The leaf, stem and pod biomass improved at harvest in all the treatments with moisture stress compared with irrigated controls. Under moisture stress condition, higher leaf and pod biomass was obtained at 700ppm level of CO_2, where as higher stem biomass was recorded with 550ppm level of CO_2. However, root biomass in general was the most affected component in all the treatments with moisture stress and the reduction was much higher at 700ppm.

Figure 4. Change in dry weight of different components of groundnut
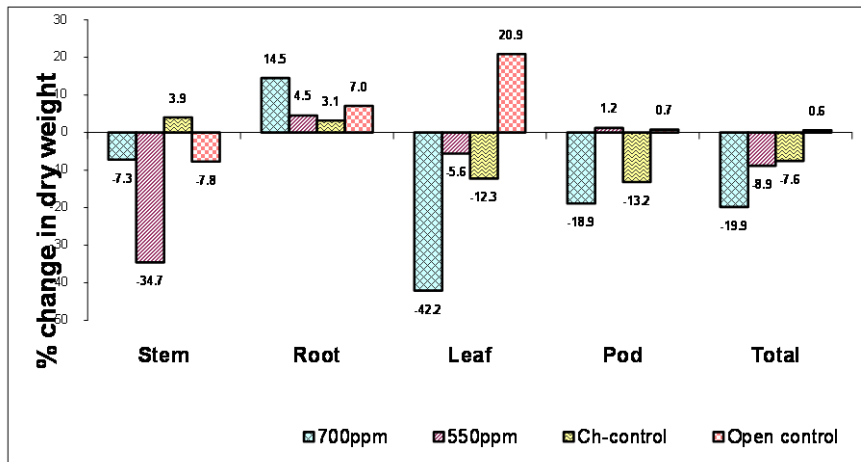
Moisture stress has no effect on number of pods per plant but it improved the seed number and seed weight in all the treatments. There was no significant difference in

biomass with moisture stress under open field conditions but there was significant decrease in the pod yield. The chamber conditions in general reduced the biomass production compared with open field conditions.

The crop raised in OTCs during *Kharif* season received rainfall of 259.4 mm in 19 rainy days and without any prolonged dry spells during crop growth period. The leaf area and biomass of shoot, root and leaf in groundnut crop was highest at 700ppm level CO_2 followed by 550ppm and Ch-control at all stages of growth. Days to flower initiation was reduced by one day with 700ppm CO_2 level but days to 50% flowering was reduced by three days with higher levels of CO_2. The increased CO_2 levels improved the biomass at harvest and number of pods per plant (Table 6). At 700ppm CO_2 level on an average 17 pods/plant were harvested which was 24% higher than Ch-control. The number of seed also increased by 36% at 700ppm and 7% at 550ppm

Table-6: Seed yield of groundnut under different levels of elevated CO_2 (700, 550ppm), ambient chamber control and open control-Kharif 2007

Parameters	Conditions			
	700ppm	550ppm	Ch-Control	Open Control
Total plant biomass (g)	13.11	9.69	8.31	16.76
No. of pods	17.4	14.7	13.3	12.8
Pod dry wt. (g/pl)	6.65	6.49	5.98	7.02
Seed wt. (g/pl)	4.31	4.28	3.86	3.20
100 Seed wt. (g/pl)	32.35	46.72	45.36	29.57
HI %	32.9	44.2	46.4	19.1

The higher biomass of groundnut crop with open control conditions has not contributed to the pod yield hence resulted in lesser seed yield and lower HI.

The elevated CO_2 levels improved the percentage of oil in groundnut and this was more prominent with 700ppm (Fig. 5). The difference in protein content and total nitrogen of seed was found to be non significant with increased CO_2 levels, however a decrease in sugar content in seed was found with increased CO_2 levels.

Fig. 5. Groundnut seed quality with different CO2 levels-
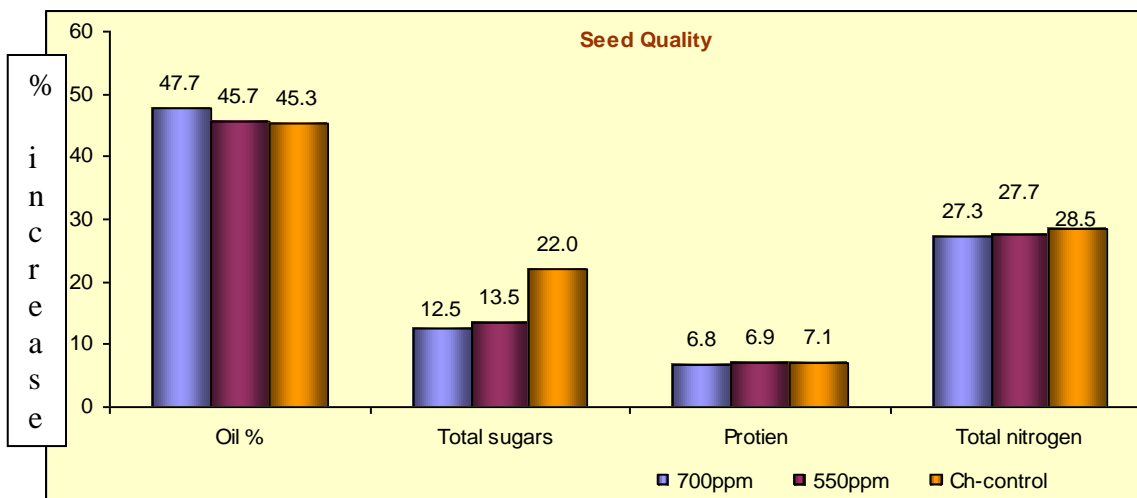
N summary, groundnut crop showed positive response to elevated CO_2 levels for growth and yield and the response was significantly evident at 700ppm. The responses of different plant components of groundnut crop were found to be different with CO_2 levels and moisture stress. Moisture stress at initial stages improved the total biomass and pod yield in all the treatments and the response was more at higher levels of CO_2.The seed weight increased with moisture stress due to higher number of pods and seeds, however reduced 100 seed weight was observed with moisture stress. Both elevated CO_2 levels increased the oil content and the response was more prominent at higher level.

The unsaturated fatty acids increased over saturated fatty acids with elevated CO_2 levels. It was also observed that the content of Oleic acid showed increasing trend with elevated CO_2 levels where as the reverse trend was with linolenic acid fraction.The chamber conditions in general reduced the biomass production (up to 50%) during both *Rabi* and *Kharif* seasons compared with open field conditions.

Indian Institute of Horticultural Research, Bangalore

The data on soil properties, crop management practices and yield levels were collected for Nasik, Bhavnagar, Rjakot, Junagadh and Karnal for onion and Bhubaneshwar and Ludhiana for tomato. Daily weather data for Bhavnagar, Bhubaneshwar, Varanasi and Nasik was collected from IMD, Pune.

Calibration and validation of Info-crop tomato and onion models
The adopted InfoCrop simulation models for tomato and onion were further calibrated. The models were calibrated from the data obtained from field experiments conducted at IIHR, Bangalore for determinate and indeterminate cultivars of tomato and four important cultivars of onion grown under potential conditions. The information was also used from published literature on these crops. Validation of the models was taken up with the inputs from experiments conducted at different agro-ecological regions for different seasons, nitrogen and irrigation levels. The data from experiments conducted at Bangalore, Hyderabad, Hisar, New Delhi, Dharwad and Nasik were used for validating onion model and data from Bangalore, Karnal, Ludhiana, Bhubaneshwar and Hisar for validating tomato model.

Collection of data for model input requirements
Sensitivity analysis of the models
The sensitivity analysis of the validated models was done to quantify the impact of increase in temperature and CO_2 on yield. The changes in maximum and minimum temperatures by one-degree increment and CO_2 by 50 ppm were used for the simulation. It was observed that the yield reduction in tomato was only up to 20% when the temperature increased up to 5°C. In onion the yield reduction was up to 40% with increase in temperature of 3°C and 75% reduction with 4°C increase (Fig.1).
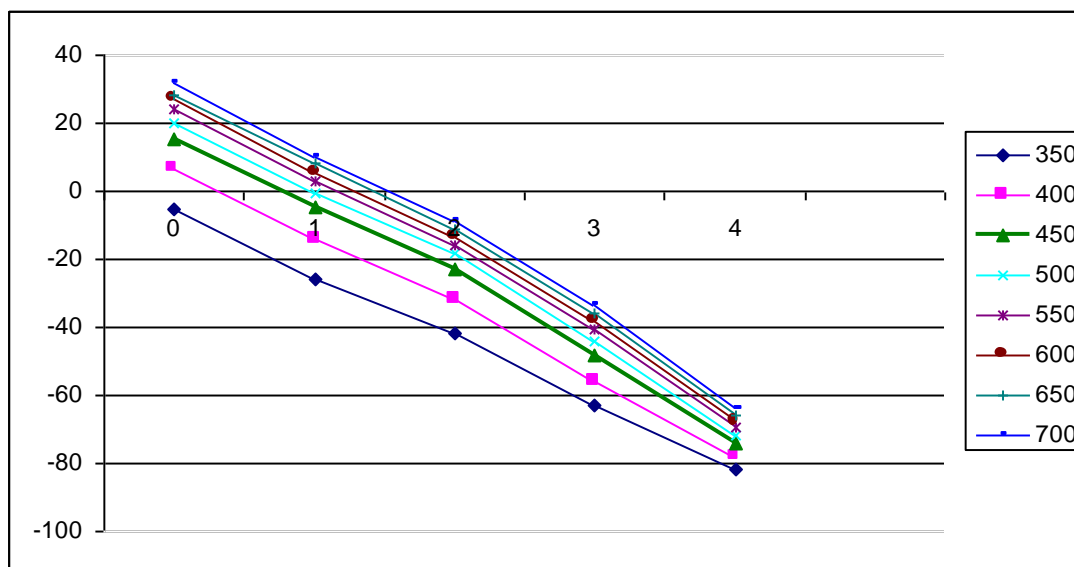
Fig 1. Percent reduction in onion yield due to incremental changes in temperature and CO_2

Analysis of the impact of climate change on onion and tomato yields under different scenario

The analysis of the impact of climate change on tomato and onion yields under different scenario using HADCM3 data for A2a scenario for baseline, 2020, 2050 and 2080 time slices was done for different growing areas.

Impact of climate change on tomato yield

The analysis of the impact of climate change on tomato yield was done using the InfoCrop model for Bangalore, Belgaum, Dharwad and Kolar districts of Karnataka, Bhubaneshwar in Orissa and Ludhiana in Punjab for Kharif, Rabi and Summer seasons. Standard package of practices followed and characteristics of the soil dominant in these areas was considered for the study. Only the climate data was changed for different areas and model was run individually for each area for the baseline and climate change scenario 2020, 2050 and 2080. The impact of the climate change in terms of deviations in yield for 2020, 2050 and 2080 from base years is presented in the table 1.

Table 1. Deviations in Tomato yield for 2020, 2050 and 2080 from base year

District	Season	2020	2050	2080
Bangalore	Kharif	-02.84	-10.33	-24.75
	Rabi	-01.29	-02.19	-03.93
	Summer	-03.04	-10.41	-23.78
Belgaum	Kharif	-10.86	-23.97	-58.27
	Rabi	-00.40	-14.73	-34.42
Dharwad	Kharif	-15.56	-45.76	-64.44
	Rabi	+04.25	-14.24	-39.22
Kolar	Kharif	-03.12	-12.32	-25.18
	Rabi	-01.98	-03.21	-05.03
	Summer	-03.98	-12.22	-25.98
Bhubaneshwar	Rabi	-04.12	-18.99	-62.61
Ludhiana	Rabi	+12.94	+32.57	+37.23

The data indicated that areas like Bangalore rural and Kolar districts where current temperature conditions are milder, the reductions in Rabi yields are going to be marginal to the tune only of 5% during 2080. Whereas, during Kharif and summer seasons the maximum yield reductions will be around 26% during 2080. In districts like Belgaum and Dharwad, the reductions in yield will be considerable in 2050 and 2080 even during Rabi season. However, during 2020 the yield reductions are negligible in Belgaum. Whereas, under Dharwad conditions, there would be an increase of 4.25 %

yield. The Kharif season yields are likely to be affected to the tune of 64.44% in Dharwad district during 2080. In Bhubaneshswar area also the yield reductions would be considerable during 2050 and drastic during 2080. Under Ludhiana conditions, where the prevailing Rabi season temperatures are lower, the yields during Rabi season would increase for all the time slices studied.

Table 2. Impact of climate change on Onion yield under different climate change scenarios

Region	Season	Percent change in yield relative to base year								
		2020			2050			2080		
		A2a	A1F	B2a	A2a	A1F	B2a	A2a	A1F	B2a
Nasik	Kharif	-11.71	-14.09	-12.89	-26.22	-32.45	-15.88	-45.27	-57.88	-29.40
	Late Kharif	-07.13	-10.05	-6.61	-19.84	-28.57	-09.80	-39.60	-58.80	-26.52
	Rabi	-03.34	-04.63	-03.33	-11.55	-17.10	-08.54	-27.59	-38.59	-16.44
Bhavnagar	Rabi	-08.60	-11.92	-08.80	-21.02	-30.31	-16.73	-40.23	-60.12	-22.76
Junagadh	Rabi	-12.43	-15.60	-13.50	-31.40	-42.35	-25.04	-54.67	-73.83	-33.10
Karnal	Rabi	+00.82	+05.57	+00.81	+17.30	+04.66	+13.83	+03.25	-1.62	+14.70
Chitradurga	Rabi	-10.79	-10.81	-11.09	-28.55	-32.22	-24.75	-50.80	-67.07	-38.73

Impact of Climate Change on Onion Yield

Impact of climate change on onion yield was analysed using the InfoCrop model for major onion growing regions for different scenarios (A2a, A1F, B2a,) of climate change (HadCM3 model) for 2020, 2050 and 2080. The study regions were, Nasik in Maharashtra for Kharif, Late Kharif and Rabi seasons, Bhavnagar and Junagadh in Gujrat and Karnal in Haryana and Chitradurga in Karnataka, for Rabi season.

The model outputs showed that, in Nasik region of Maharashtra, a major onion growing region, yields reductions would be more in Kharif season followed by Late Kharif season. Yield reductions would be lowest in Rabi season in 2020, 2050 and 2080 for the all the scenarios studied. The other major onion growing region, Bhavnagar and Junagadh in Gujrat, where major crop is taken during Rabi season also showed yield reductions. The yield reductions would be higher in Junagadh area as compared to Bhavnagar area under all the scenarios, with considerable reductions in yield during 2080. Whereas, under Karnal conditions there would be negligible increase in yield during 2020 under A2a and B2a scenarios and 5.57% increase under A1F scenario. There would be an increase in yield of 4.66 to 17.30% during 2050 under different scenarios. However, this advantage would be lost during 2080 and only 3.25% increase would be observed under A2a scenario and there would be a yield reduction of 1.62% under A1F scenario. But, under B2a scenario there would be 14.70% increase during 2080. Under Chitradurga area

in Karnataka for Rabi season, the yield reductions would be 10.79 to 11.09% during 2020. But subsequently during 2050 and 2080 the yield reductions would be very high.

Impact of Elevated CO_2 on growth and yield of tomato and Onion
Carbon dioxide enrichment studies

Fig.2 OPEN TOP CHAMBERS FOR CO_2 ENRICHMENT STUDIES ESTABLISEHD AT IIHR, BANGALORE

Response of onion and tomato to elevated CO_2 (550ppm) was studied in Open Top chambers. Two OTCs were maintained at 550 ppm and two were maintained at ambient level (365ppm) without any external CO_2 supply as chamber control (Ch-control). The CO_2 concentrations were maintained and continuously monitored during experimental period. The observations on shoot dry weight, leaf area and total biomass were recorded at 20, 40, 60, 80, and 100 DAP. For each treatment three plants were sampled in three replications from each chamber. The shoot dry weight increase at 550 ppm CO_2 was highest at 70 DAP (80%) over chamber control. Leaf area increased from 20 to 90 DAPS in all the treatments. Under elevated CO_2, maximum leaf area of 11.27 dm^2 was observed compared to 5.97dm^2 in Ch-control. Elevated CO_2 levels enhanced the total biomass at all growth stages. Total biomass was maximum at 100DAP (18.6 g/plant) compared to control (13.40g/plant). The percent increment in total biomass at elevated CO_2 varied from 52 to 81 % at different growth stages. In onion increase in photosynthetic rate varied from 19.4 to 64.60 % during bulb development stage (Table 3). There was a reduction in stomatal conductance indicating better water use efficiency at elevated CO_2. A yield increase of 25.9 % was observed at elevated CO_2over control. Yield increase was

mainly due to increase in the bulb size. The data on quality parameters showed that there is a decrease in the antioxidant content at elevated CO_2. Total phenols were higher and a decrease in flavonoids content was observed.

In tomato cv.Ashish there was an increase in the photosynthetic rate by 23% at the vegetative, 51% at the flowering and 68% during the fruiting stage. Stomatal conductance decreased at all the stages at 550ppm CO_2 compared to ambient CO_2 (365ppm) (Table 4).Transpiration rate also decreased at different stages at 550 ppm CO_2. LAI was 4.36 and 2.71 at 550 ppm CO_2 compared to chamber control 4.25 and 1.22 at the flowering and fruiting stages, respectively. Per plant yield at elevated CO_2 was 3.03 Kg/Plant compared to plants grown at ambient CO_2 (2.62 Kg/plant). Yield increase was mainly due to increase in the number of fruits per plant at elevated CO_2 (74 fruits/plant) compared to chamber control (56 fruits/plant). A yield increase of 24.4% was observed at elevated CO_2 concentration compared to chamber control. Quality parameters were also studied. There was a significant increase in the lycopene and carotenoid content at elevated CO_2 (Table 5).

Table 3. Photosynthesis (μmol m^{-2} s^{-1}), Stomatal conductance (mol m^{-2} s^{-1}) and transpiration rate (mol m^{-2} s^{-1}) of onion at elevated and ambient CO_2

Days after Planting	Photosynthesis	Stomatal Conductance	Transpiration
550 ppm			
20	8.654	0.124	2.822
40	11.818	0.198	6.936
60	21.108	0.205	15.30
80	17.740	0.710	11.354
100	16.000	0.332	9.160
365ppm			
20	8.216	0.220	3.318
40	9.896	0.294	9.314
60	12.890	0.396	19.045
80	9.480	1.022	12.568
100	9.720	0.698	10.840

Table 4. Photosynthesis (µmol m^{-2} s^{-1}), Stomatal conductance (mol m^{-2} s^{-1}) and transpiration rate (mol m^{-2} s^{-1}) of tomato at elevated and ambient CO_2

Growth stage	Photosynthesis	Stomatal Conductance	Transpiration
550 ppm			
Vegetative	23.52	0.39	5.23
Flowering	27.40	0.34	9.86
Fruiting	37.63	0.95	7.79
365 ppm			
Vegetative	19.12	0.61	6.13
Flowering	18.15	0.48	11.87
Fruiting	22.40	1.24	7.79

Table 5.Quality parameters in onion and tomato at elevated and ambient CO_2
a) Onion

Parameter	OTC(550ppm)	OTC (365ppm)
Anthocyanin	21.29	20.68
(mg/100 g dry wt)	20.50	20.79
Mean	20.90	20.73
Total Phenols	495.44	471.96
	498.33	470.80
Mean	496.89	471.38
Flavonoids	23.53	25.96
	21.06	32.88
Mean	22.29	29.42
Antioxidant	135.37	162.01
	136.69	162.46
Mean	136.03	162.24

b) Tomato

Pickings	II	III	IV	II	III	IV
Parameter	OTC(550ppm)			OTC (365ppm)		
Carotenoids	8.15	9.0368	10.9642	5.84	8.472	5.9375
(mg of β carotene eqt /100g)	8.13			5.87		
Mean	8.14	9.0368	10.9642	5.855	8.472	5.9375
Lycopene	5.52	6.8017	9.2907	3.83	6.4519	4.3357
(mg of lycopene /100g)	5.51			3.84		
Mean	5.515	6.8017	9.2907	3.835	6.4519	4.3357
Total Phenols	3.0863	3.4689	2.9751	3.7529	4.3825	3.3208
(mg of gallic acid eqt/100g)	4.2714	4.1109	2.8023	4.3454	4.9257	2.6665
Mean	3.6788	3.7899	2.8887	4.0492	4.6541	2.9937
Flavonoids	0.3375	0.4725	2.3625	0.3375	0.135	1.0125
(mg of catechin eqt/100g)	0.2025	0.27	1.89	0.27	0.0675	1.89
Mean	0.27	0.3713	2.1263	0.3038	0.1013	1.4513
Antioxidants	13.64	14.2384	9.9968	14.3088	15.2416	10.8416
mg of AEAC units/100g)	13.9568	13.8336	12.0912	16.2448	13.3936	9.9264
Mean	13.7984	14.036	11.044	15.2768	14.3176	10.384
TSS (%)		3.00			2.80	

Studies on the relationship between temperature, phenology and quality of grapes grown under different grape growing regions

The data on days taken for cv. Cabernet Sauvignon for different phonological stages viz., bud break, flowering, veraison and harvest maturity was collected for Nasik, Bangalore, Bijapur and Sangli areas (Table 3). The data showed that there are differences in days taken for veraison and harvest maturity among the grape growing areas. The fruit samples from vineyards pruned at different dates from these areas were collected and analysed for fruit quality parameters. The relationship between maximum, minimum and difference between maximum and minimum temperatures and quality parameters were parameters were worked out.

Table 6. Days taken for cv. Cabernet Sauvignon for different phonological stages in grape growing regions

Region	Pruning period	Days to bud burst	Days to flowering	Days to veraison	Days to harvest
Nasik	Sept 4th week	10-12	40	80	161-165
	Oct 1st and 2nd week	10	40	85-94	164-172
Bangalore	Oct last week	14	42	97	164
	Nov 1st and 3rd week	12-14	40-42	96-98	178-182
Bijapur	Oct 1st week	10	40	88	162
Sangli	Sept 3rd week	10	40	93	167
	Oct 1st week	10-11	40	91	164-165

a) Relationship between mean maximum temperature and anthocyanin content

$y = -23.859x + 943.82$
$R^2 = 0.8505$

b) Relationship between mean minimum temperature and anthocyanin content

$y = -23.086x + 457.35$
$R^2 = 0.871$

c) Relationship between difference in maximum and minimum temperature and anthocyanin content

$y = 22.324x - 235.2$
$R^2 = 0.9345$
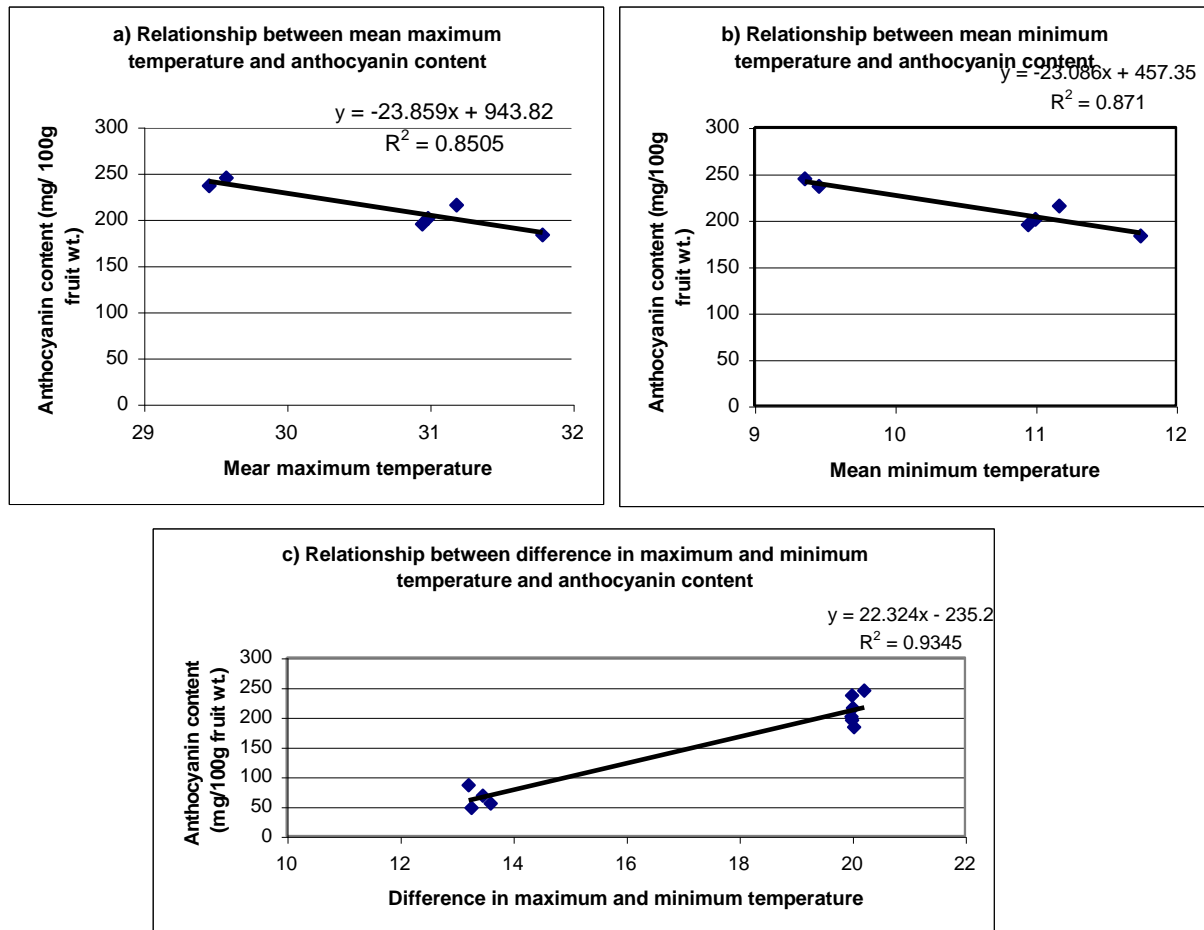
Fig.4 Relationship between mean maximum (a) minimum (b) and their difference (c) and berry antocyanin content of cv. Cabernet Sauvignon

The relationship between mean maximum and minimum temperature during veraison to fruit maturity stage and berry anthocyanin content showed a negative relationship. The increase in both maximum and minimum temperatures caused reduction in the berry anthocyanin content significantly at harvest. The difference between maximum and minimum temperature during the fruit maturation stage was found to has very high influence on berry anthocyanin content. Higher the gap between maximum and minimum temperatures, higher was the anthocyanin content. This relationship has greater bearing on the anthocyanin content under climate change conditions. Though both maximum and minimum temperatures would be increasing, the increases in minimum temperature would be higher, thereby reducing the difference between maximum and minimum temperature in turn affecting the quality.
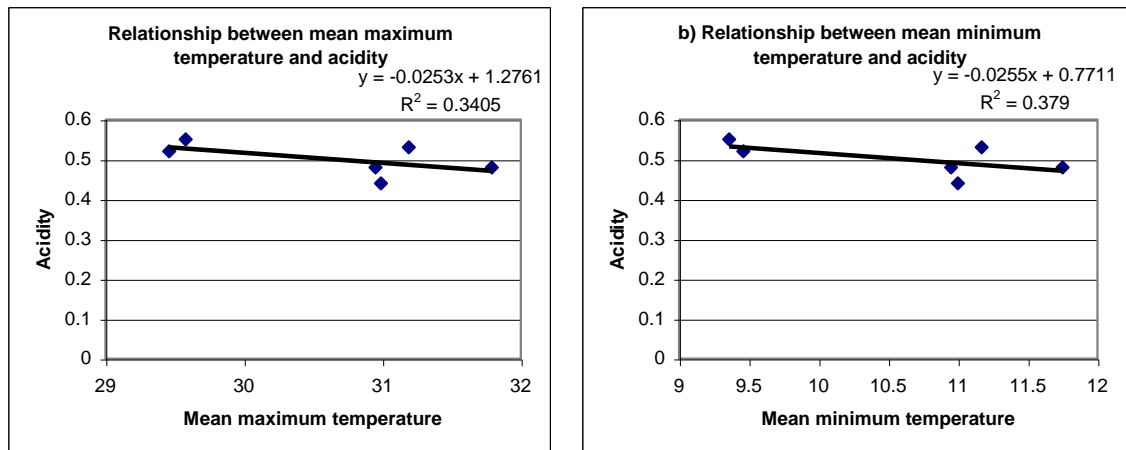
Fig. 5. The relationship between mean maximum (a) minimum (b) and berry juice acidity

Tough the influence of both mean maximum and minimum temperature on acidity was non significant there was a negative relationship. The reduction in acidity was noticed due to increase in both maximum and minimum temperatures.
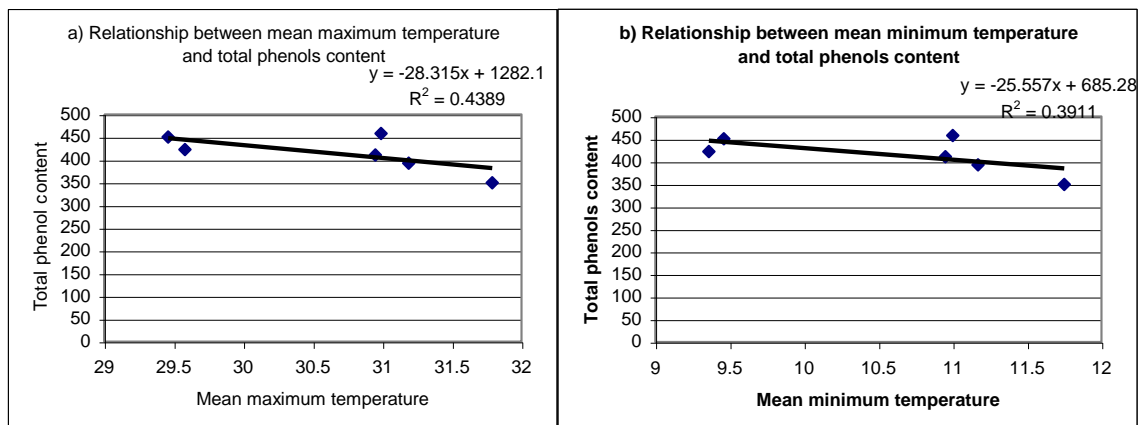
Fig. 6. The relationship between mean maximum (a) minimum (b) temperatures on berry total phenol content

In case of berry total phenol content also, tough the influence of both mean maximum and minimum temperature was non significant but there was a negative relationship. The reduction in total phenol content was noticed due to increase in both maximum and minimum temperatures.
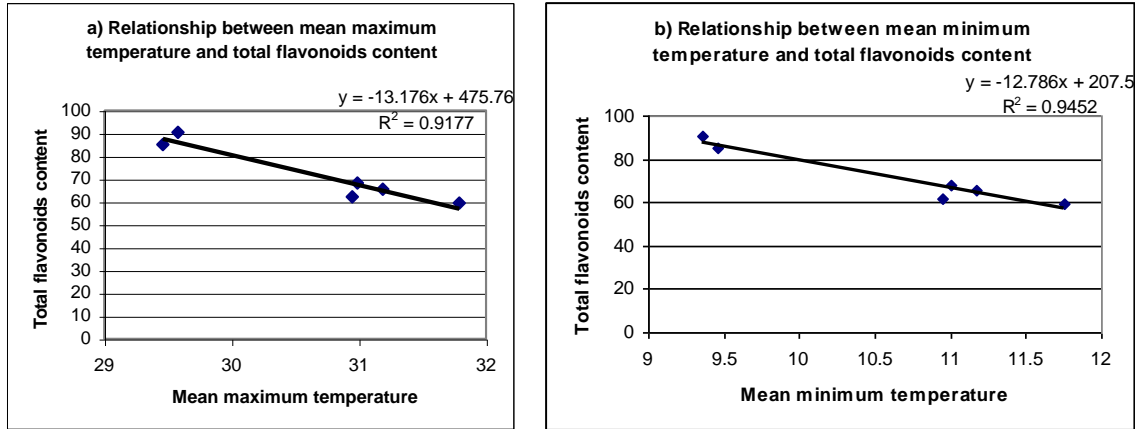
Fig. 7. The relationship between mean maximum (a) minimum (b) and berry total flavonoids content

The relationship between mean maximum and minimum temperatures and berry total flavonoids content showed a very significant relationship. The increase in both maximum and minimum temperatures caused the reduction in berry total flavonoids content.

These relationships worked out between the prevailing mean maximum and minimum temperatures during the fruit maturation phase (veraison to harvest) have greater significance in assessing the impact of climate change on grape fruit quality. The increases in both maximum and more so in minimum temperature would have considerable effect on the quality parameters of grapes cv. Cabernet Sauvingon thereby leading production of poor quality fruits.

Plant performance and yield components in onion grown under different plant spacings

A study was conducted to determine the plant performance and yield components in onion grown under different plant spicings in the field during Rabi season. 35 days old seedlings were transplanted in the field in four plant spacings i.e. close spacing, 8.0x8.0 cm, 10.0x10.0 cm, and 12.0x12.0 cm. The observations were made on leaf area production, leaf area index (LAI), total plant dry matter and its distribution to different plant parts and bulb yield.

a) Leaf area index and bulb yield:

The leaf area index (LAI) was determined at 74 days after transplanting (DAT). The leaf area (LA) was more (24953.4 cm^2/ m^2 area) in the plants grown in 8.0x8.0 cm spacing, while in close space planting the leaf area was 19762.72 4 cm^2/ m^2 area. The LAI varied from 1.86 in 10.0 x10.0 cm spacing to 2.5 in 8.0 x 8.0 cm. The LAI in close spacing was 1.98. The bulb yield was observed about 6.0 kg/m^2 area in 8.0 x 8.0 cm and

10.0 x 10.0 cm spacing. In close planting the bulb yield was least i.e. 2.54 kg/m^2 area (Table 6).

Table 7. Leaf area index and bulb yield in onion grown in different plant spacing

Parameter	Close spacing	8.0 x 8.0 cm	10.0 x 10.0 cm	12.0 x 12.0 cm
Leaf area (cm2/m2 area)	19762.72	24953.40	18567.80	19154.47
LAI	1.98	2.50	1.86	1.92
Bulb yield (kg/m2 area)	2.54	5.97.	5.82	4.1

b) Total plant dry matter accumulation and its distribution to different plant parts:

The per plant dry matter ranged from 1.270 to 3.136 g/plant in different spacing. Maximum plant dry matter production (3.136 g/plant) was observed in 10.0 x 10.0 cm spacing. The partitioning to bulb was least (28.0%) in the close space planting, while in other spacing the partitioning to bulb was about 45.0%. In close planting the maximum proportion of dry matter partitioned to stem followed by bulb and leaf, while in other spacing the maximum dry matter partitioned to bulb followed by leaf and stem.

Table 8. Total plant dry matter (g/plant) and its distribution (%) to different plant parts

Parameter	Spacings			
	Close spacing	8.0 x 8.0 cm	10.0 x 10.0 cm	12.0 x 12.0 cm
Plant dry matter	1.270	2.001	3.136	2.630
Leaf	23.50	32.37	28.35	31.02
Stem	48.59	22.31	26.39	23.74
Bulb	27.91	45.32	45.26	45.24
* Observation at 74 DAT				
Yield is recorded at final harvest				
Dry matter partitioning to different parts of onion plant in different spacing under field condition				

Parameters	Spacings			
	Close planting	8X8 cm	10X10 cm	12X12 cm
TDM(g/plant)	2.142	2.001	3.136	2.63
Leaf dry weight (%)	34.48	32.37	28.35	31.02
Stem dry weight (%)	24.59	22.31	26.39	23.74
Bulb dry weight (%)	40.93	45.32	45.26	45.24

CSK Himachal Pradesh Agricultural University, Palampur

Impact of climate change on crops:

Maize:

The INFOCROP-maize model was validated using the historical data generated by the research trials at Palampur. The weather data and soil data already generated was used. Impact of elevated CO_2 on maize yield was simulated under both potential i.e., no resource limitation and rainfed under recommended package and practices under sub humid and subtropical region of Palampur. Results showed that the magnitude of impact of elevated Co_2 was more under rainfed conditions. Under potential conditions, an increase in CO_2 to 420ppm and 470ppm levels indicated an increase of more than 3.0% and 5.4% in 10th June sown crop over current CO_2 levels (Table 1 & Fig 1). The subsequent planting windows on 20th June showed 3.8 and 6.3% increase in yield under 420ppm and 470ppm CO_2 levels.

The highest yields under potential conditions were obtained on 10th June sown crop at all levels of CO_2 based on Probability Distribution Function. Similarly under Rainfed Conditions the best planting was 10th June. It is also supported by the weather data of the region as Palampur region receives pre-monsoon rains during first week of June which is best for sowing of crop.

Under rainfed conditions 420ppm and 470ppm levels indicated an increase of more than 4.3 and 8.1% in 10th June sown crop (Table 2).The elevated CO_2 levels i.e. 420 and 470 ppm showed an increase in yield. The rainfed crop was simulated under recommended packages and practices.

Table 1. Impact of elevated CO_2 on Maize Yield under No Resource Limitation in Sub Humid Subtropical Conditions. (Based on 20 Years).

Date of Sowing	CO_2 Impact			Percent Change in Yield	
	370	420	470	420 ppm	470 ppm
10th June					
Mean	6448.35±1096	6643.07±1042	6794 ±1252	3.0	5.4
Maximum	10989	113450	12446		
Minimum	5610	5834.0	5937.0		
20th June					
Mean	6000.0±1288	6230.0±1083	6379.0±1259	3.80	6.3
Maximum	10132	12306.0	1241.0		
Minimum	5795	6263.0	6802.0		
30th June					
Mean	5892.0±1273	6094±1110	6149.0±1245	3.4	4.4
Maximum	8997	98763.0	99270		
Minimum	5858	5913.0	6058.0		

Table 2. Impact of elevated CO_2 on Maize Yield under Rainfed Condition (Palampur). (Based on 20 Years)

Date of Sowing	CO_2 Impact			Percent Change on Yield	
	370	420	470	420 ppm	470 ppm
10th June					
Mean	6044.6±1221	6287.1±970	6531.97±686	4.3	8.1
Maximum	7517.7	7648.0	7761.0		
Minimum	4702.0	3301.9	5604.0		
20th June					
Mean	5765.0±1084	5942.5±1110	6047.48±874	3.00	4.90
Maximum	7938.0	8090.6	8241.3		
Minimum	4197.2	4230.2	4232.0		
30th June					
Mean	5724.0±1257	5882.5±1292	5992.2±1306	1.2	4.70
Maximum	7524.0	7683.0	7300.0		
Minimum	3568.0	3605.0	3658.7		
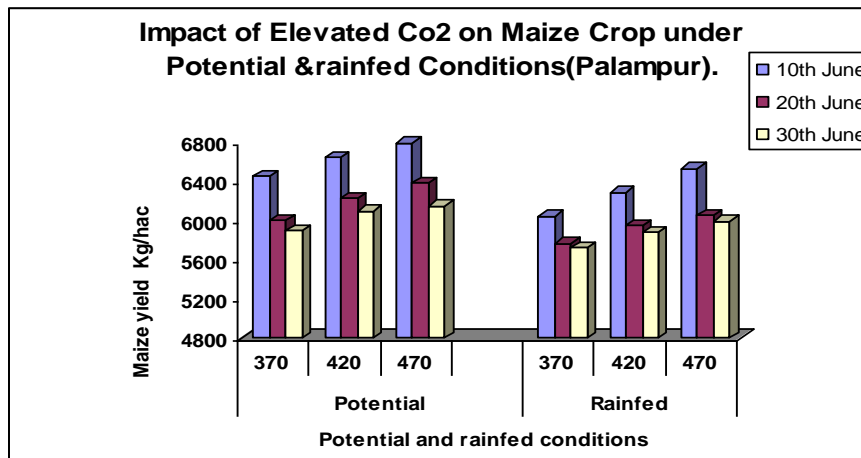
Fig 1. Impact of Elevated CO_2 on Maize Crop under Potential Conditions

Impact of Temperature and Rainfall

The impact $1^{o}C$ and $2^{0}C$ rise temperature was simulated for maize crop at 370ppm Co_2 levels (Table 3 & Fig 2).The result showed decrease in yield due to increase in both maximum and minimum temperature by $1^{o}C$ and $2^{o}C$ rise and 2-10% reduction in rainfall. The magnitude of decrease was higher at 20th June (6 & 10.4) and 30th June (5.0 & 10.0) sown crop. However the average reduction in yield was 2-4quantals/ha under 10th June, 3-6 q/ha-30th June and 3-6 q/ha in 30th June sown crop. The magnitude of increase yield in subsequent planting windows was less. The results showed the best

planting window was around 10th June based on 20 years weather data under both potential and rainfed conditions (Table 4 &5).

Table 3 Impact of Climate Change on Maize Yield under Rainfed Condition in Palampur (Based on 20 Years).

Date of Sowing	CO_2 Impact			Percent Change on Yield	
	370	370 (AvT +1 ^{o}C)	370 (AvT +2°C)	+1°C	+2°C
10th June					
Mean	6044.6±1221	5828.2±1172	5631.97±686	-4.00	-7.0
Maximum	7517.7	6823.0	7761.0		
Minimum	3702.0	3244.0	5604.0		
20th June					
Mean	5765.0±1084	5405.23±1110	5160.0±1130	-6. 0	-10.4
Maximum	7938.0	7033.7	6103.0		
Minimum	4232.0	3622.6	3452.6		
30th June					
Mean	5724.0±1257	5440.0±1292	5124.9±1306	-5. 0	-10.5
Maximum	7524.0	7780.0	7485.0		
Minimum	3568.0	2046.5	1984.0		

Table 4 Planting Windows for Maize under Potential and Rainfed Condition at Palampur (Based on 20 Years).

Elevated CO_2 Level	10th June		20th June		30th June		Best Yield	
	No Resource Limit	Rainfed	No Resource Limit	Rainfed	No Resource Limit	Rainfed	No Resource Limit	Rainfed
370	6448.35		6000	5765.0	5892	5724.0	10th June	10th June
420	6643.07	6287.1	6230.0	5942.5	6094	5882.5	10th June	10th June
470	6794.0	6531.9	6379	6047.4	6149	5992.5	10th June	10th June

Table 5. Percent Gap in Maize Yield under Potential and Rainfed Condition in Palampur (Based on 20 Years).

Date of Sowing	No Resource Limit	Rainfed	% Gap
10th June	6448.35	6044.6	21.5
20th June	6643.07	6287.1	28
30th June	6794.0	6531.9	28
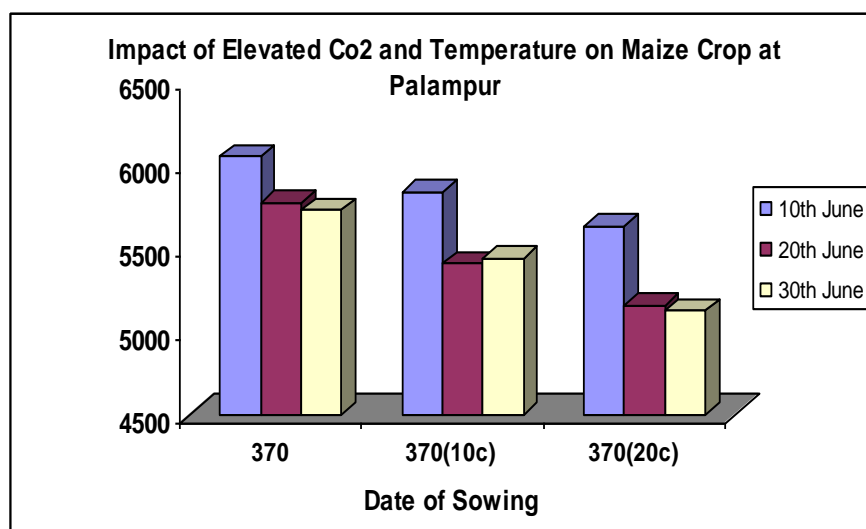
Fig 2. Impact of Elevated CO$_2$ and temperature on Maize Crop in Palampur.

Dhaulakuan Region: This site is located in district Sirmour of Himachal Pradesh. The area is located at 30°50' N latitude and 77°25' E longitude. The elevation of this site is less than 700 m amsl. Cereal and vegetable cropping are the dominant systems of this region. The regions have low to mid-hill in the southern aspect. Based on 17 years of data base the climate of the region is Sub-tropical type maximum temperature remains above 30°C during April to October and more than 19.5°C in the remaining months. Monthly average minimum temperature varies between 4.3°C to 9.4 °C from November to March and 13.6°C to 24.2°C in remaining part of the year. Annual average rainfall 1635mm SW-monsoon is the dominant rainfall receiving season however, winter rains are also received in the region due to western disturbances. The climate is represented by the subtropical and tropical conditions. The maize crop is widely grown in the area. Impact of Elevated Co$_2$. The InfoCrop-maize growth model validated at Palampur region was used for Dhaulakuan conditions.

Impact of elevated CO_2 levels on yield

The two higher levels of CO_2 420 and 470 ppm were tried under both potential and rainfed conditions.Under no resource limitations conditions the magnitude of increase was higher at 470 ppm elevated CO_2 level. The best yield was obtained at 10th June planting window under potential conditions. In all the planting windows maize yield registered an increase in yield with increase in CO_2 levels of 420 and 470ppm.(Table 6 & Fig 6).

Under rainfed conditions the yield trends showed increase with increase in CO_2 levels. There is an increase of 1-2 q/ha increase in yield due to CO_2 levels. The best yield was obtained in 20th June sown crop. Whereas under potential conditions crop gave highest yield on 10th June. On 20th June planting windows showed an increase of 2.4 and 4.1% respectively at 4200 and 470ppm elevated CO_2 levels (Table 7).
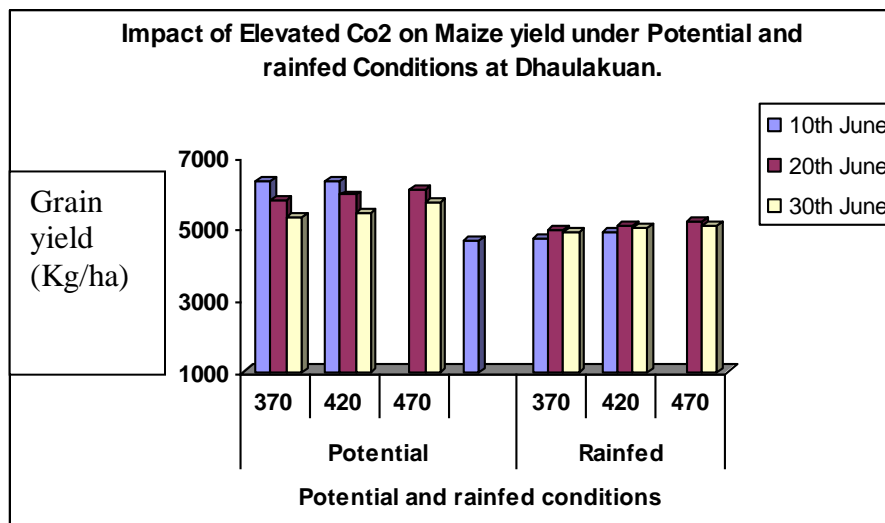
Fig 3. Impact of Elevated CO_2 on maize Yield under Potential
Conditions at   Dhaulakuan

Table 6. Impact of Co₂ on Maize yield (Kg/ha) under No Resource Limitation at Dhaulakuan (Based on 17 Years).

Date of Sowing	CO$_2$ Impact			Percent Change on Yield	
	370	420	470	420 ppm	470 ppm
10th June					
Mean	6128±1194	6290±1285	6336±1263	2.60	3.4
Maximum	6896.7	6997	7806.5		
Minimum	3991.1	3992.1	4355.2		
20th June					
Mean	5757±1220	5926±1552	6058±1439	2.9	5.2
Maximum	7052.4	7186.5	7587.0		
Minimum	3449.0	3629.3	3673.0		
30th June					
Mean	5297±1338	5410±1397	5696±1370	2.1	7.5
Maximum	7088.7	7123.4	7542.8		
Minimum	2764.3	2832.2	2666.8		

Table 7. Impact of Elevated CO$_2$ on Maize under Rainfed Conditions (Dhaulakuan). (Based on 17 Years).

Date of Sowing	CO$_2$ Impact			Percent Change on Yield	
	370	420	470	420 ppm	470 ppm
10th June					
Mean	4670±1072	4734±1112	4869±1103	1.4	4.3
Maximum	6810.7	6925.4	7027.8		
Minimum	3296.1	3340.6	3382.1		
20th June					
Mean	4970±1362	5089±1361	5173±1382	2.4	4
Maximum	6917.7	7052.4	7186.5		
Minimum	2871.2	2939.0	3007.1		
30th June					
Mean	4888±1288	4982±1305	5084±1323	1.9	4
Maximum	6963.4	7088.7	7213.4		
Minimum	2697.0	2764.3	2832.2		

Table 8. Planting Windows for Maize under Potential and Rainfed Condition at Dhaulakuan. (Based on 17 Years).

Elevated CO$_2$ Level	10th June		20th June		30th June		Best Yield	
	No Resource Limit	Rainfed	No Resource Limit	Rainfed	No Resource Limit	Rainfed	No Resource Limit	Rainfed
370	6128	4670	5757	4970	5297	4888	10th June	20th June
420	6290	4734	5926	5089	5410	4982	10th June	20th June
470	6336	4869	6058	5173	5696	5084	10th June	20th June

Table 9. Percent Gap in Maize Yield under Potential and Rainfed Condition in Dhaulakuan (Based on 17 Years)

Date of Sowing	No Resource Limit	Rainfed	% Gap
10th June	6336	4769	32.9
20th June	6290	4684	34.0
30th June	6128	4670	31.2

Wheat in sub humid and sub tropical conditions:
The wheat is sown under three sowings conditions; Early sown: Mid October to Mid November; Timely sown November: 10 to November 30:

Validation of Crop Model for Wheat Crop
Simulated and Observed days for wheat crop in Palampur for early sown varieties were compared. (Table 10). INFOCROP-wheat Model was validated for different planting dates. Result shows that observed days to anthesis for wheat crop at Palampur showed higher values than that of simulated values. Whereas result noticed for Simulated and observed yield showed more yield in simulated as compared to observed (Table 11).

Table 13. Simulated and Observed days to Anthesis for Wheat Crop in Palampur for Early Sown Varieties.

Planting date	Simulated	Observed
October 15,1998	152	161
October 30,1998	149	157
October 15,1999	139	147
October 30,1999	152	163
October 15,2000	128	143
October 30,2000	140	152
October 15,2001	135	151

| October 30,2001 | 145 | 159 |

Table 14. Simulated and Observed Yield for Wheat Crop in Palampur for Early Sown Varieties.

Planting date	Simulated	Observed
October 15,1998	4371.9	3362
October 30,1998	2902	3374
October 15,1999	5496	4347
October 30,1999	3737	3433
October 15,2000	5190	4425
October 30,2000	4622	3886
October 15,2001	5698	4507
October 30,2001	4666	3528

Late sown 15 December to 30 December at sub humid and sub tropical conditions of Palampur. The crop model was validated and run for 20 years and Probability Distribution Function was used for the results to evaluate the best yields. Results indicated that increase in yield with elevated levels of Co_2 was to the tune of 4.9 to 7.3 % on early sown conditions i.e 15th October (Table 15 &16). Similar increase in yield was observed on 30th October sown crops under irrigated and recommended package and practices.

Table 15. Impact of Elevated CO2 on Wheat Yield under Irrigated Condition at Palampur. (Based on 20 Years).

Date of Sowing	CO_2 Impact			Percent Change on Yield	
	370	420	470	420 ppm	470 ppm
15th October					
Mean	5426.7±1267	5694.0±1302	5820.0±1331	4.9	7.3
Maximum	9440.0	9649.0	10092		
Minimum	4578.1	4106.0	4253.0		
30th October					
Mean	4776.0±1222	4878.0±1145	5038.0±1133	2.1	5.4
Maximum	7813	9435.0	9857.0		
Minimum	2895	4014.0	4223.0		

Table 16. Impact of Date of Sowing on Wheat under Potential Condition at Palampur (Based on 20 Years).

Treatments	HS-240		HPW-147		Best Yield
	15th October	30th October	15th October	30th October	
Mean	7096.2±1319	6157.85±2211	6779.0±635	5572.0±1275	15th October HS-240
Maximum	9311.0	9726.0	8036.0	7258.0	
Minimum	5149.0	3022.0	5749.0	3665.0	

Impact of Irrigation and Temperature

The INFOCROP Model was run for 20 years under four and six irrigations for Palampur conditions. Results revealed that skipping two irrigations in wheat caused 15 to 24 % reduction in yield. (Table 14-16). One degree rise in both Max. and Min. temperature under recommended package and practices with four and six irrigations were simulated. Results indicated 10% increase in yield in six irrigation and 4.9% in four irrigation which reflected that temperature is one of factor which limit the wheat yield in this region. There was a similar result simulated on 15 October sown crop.

Table 17. Impact of irrigation on Wheat in Palampur (Based on 20 Years).

Date of Sowing	Number of irrigation		Percent Change on Yield
	Six	Four	
15th October			
Mean	6692.2 ±1219	5081.0±1220	-24.0
Maximum	8317	7856	
Minimum	4819	3546	
30th October			
Mean	4776.0±1810	4051.0±785	-15.2
Maximum	7813	4261	
Minimum	2895	1623	

Simulated and observed days for wheat crop in Palampur for early sown varieties has been observed and presented in Table 18 & 19.

Table 18. Impact of elevated temperature and irrigations on Wheat under different Irrigation level in Palampur (Based on 20Years).

Date of Sowing	No Resource Limitation	Six irrigation	Six irrigation (+1 ^{o}C)	Four Irrigation	Four Irrigation (+1 ^{o}C)
15th October					
Mean	7096.2±1319	5426.7±1267	6013.0± 974	5081.0±1220	5430.0±1602
Maximum	9311	9440.0	9494	7856	8999
Minimum	5149	4578.1	6372	3540	3047
30th October					
Mean	6157.8±2211	4776.0±1222	5303.0±1222	4051.0±785	4223.0±999
Maximum	9726	7813	7994	4216	5995
Minimum	3022	2895	2901	1628	2508

Table 19. Impact of date of sowing on Wheat under Potential Condition at   Palampur (Based on 20 Years).

Treatments	Six irrigation & +1°C		Four irrigation &+1°C		Percent change	
	Six irrigation	Six irrigation(+1)	Four Irrigation	Four Irrigation(+1)	Six irrigation	Four irrigation
15 October	5426	6013	5081.0	5430.0	10.0	4.9
30 October	4776	5303	4051	4223	11.0	4.2

Farmers' perception regarding growing of Maize crop (Table 20&21)

Farmers' perceptions regarding growing of maize crop has been studied. Eighty seven percent of the farmers reported that generally maize crop does not fail. Eighty nine percent of the farmers reported that maize crop fails if rains fail in the month of June. Delay monsoon also resulted in crop failure. Delay in crop sowing also resulted into crop failure as reported by 93 percent of the farmers. Eighty six percent of the farmers used gap filling practice for crop improvement. Maize crop generally does not fail in Dhaulakuan. Maize + Legume is general practice. Ragi + soybean is generally grown.

 In the event of rains failure for 15 days in June month crop yield reduced. Earthing up and channels are made to save crop from water stress. After tasseling one to two leaves below cobs are removed to save from drought in the month of August. Crop yields reduce due to delay in sowing in June. In Palampur Crop yield reduce due to heavy and continuous rains. Less rains resulted in more yield is the general perceptions of the

farmers of the region. Delay in sowing cause the major reduction in yield. Leaves removal is one of the practices if dry spell occurs in August. Less time available in SW monsoon for intercultural operations due to heavy rains. The farmer perceptions indicated that if dry spell occur in July than Earthing up and Gap Filling is done. Where in August, the leave below cobs immediately after tasseling are recommended to mitigate the stress.

Central Soil and Water Conservation Research and Training Institute - Dehradun

Introduction

During the period under report, preliminary work related with the study was undertaken. The review of literature reveals that AVSWAT and EPIC models have been used by most of the workers to assess the hydrological parameters of the watersheds. EPIC gives soil erosion and crop productivity both. There appears to be significant variation in the methodology adapted by the workers all over the world. An integrated approach has been observed in most of the studies including generation of daily (scaling down) projected weather data from GCM using RCM and finally computing projected crop yield with input of not only precipitation but temperature and CO_2 .This not only warrants the knowledge of running the model but thorough basic concept of hydrology, soil, crop physiology and off course climate.

In Indian context only general information of effect of climate change over hydrology and crop production is available. Quantitative information on this aspect is rarely available. The model used for any study needs to be calibrated and validated before applied for generating projected output. The non availability of data on runoff and soil loss from watersheds of about 500 ha also puts additional use of sub model for calibration and validation.

One of the common requirements of any model for hydrological study is developing input layer of DEM, soil and land use. In order to develop DEM layer, the relevant toposheets of the study watersheds (7 numbers, Table 1) were scanned, geo-referenced on UTM projection: datum WGS 84.The watershed boundary was delineated and the contours and the boundary were digitized. The DEM was then generated on Arc-view (Fig1).

The models also need tabular data on additional parameters. Some of these data has been compiled from secondary sources as published in various literatures (Table 2). The daily weather data of the stations adjoining nearer to the study area as available with the India meteorological Department (IMD) , ICAR institutes or SAUs has been collected for a duration of 5 years (mostly for the period between 1990 -2005).This will be required for hydrological and crop models.

Groundwater recharge

The aspect of ground water recharge (a component of the rainfall –runoff relationship) is being studied at CSWCRTI, Regional Station Vasad, Gujrat since 2002-2003. This data will be used to calibrate and validate the hydrological model. The data is being reorganized/reanalyzed keeping in view the model requirement. Under this;

The data on groundwater level from 2002 September to March, 2008 have been collected (fortnightly and weekly basis). Suitable models like SWAT (Arc-view interface), and WEAP (Water Evaluation Assessment Project) has been chosen to be used for running the climate change scenario's effect on water resources. Another model GMS (Groundwater Modeling System) also has been procured to find out the groundwater recharge scenario consequent upon the climate change. The detailed geological survey is in progress using electrical resistivity method. Geological formation data (well log data) for 3 piezometers installed in the project area have been collected. A representative well log data (Fig 2.) reveals that the watershed has four aquifers of

which first and second aquifer are important from ground water recharge point of view. The software FEMWATER (a surface storage simulation module in GMS) will be used to simulate the potential recharge from surface storage structures based on the aquifer properties underlying it.
All these data will be used as inputs for climate change impact analysis on ground water recharge and soil erosion.

Table: 1. Details of the watersheds under study

S. N.	Name of the watershed	Longitude, Latitude	Area (ha)
1.	Almas, Thyathud, Dhanolty, Tehri Garhwal, Uttaranchal	78°10'- 78°13' E, 30°25'- 30°30' N	536
2.	Antisar ,Kheda, Gujrat	73°10' -73°12' E, 23°O' - 23^0 01' N	599
3.	Belura ,Akola, Maharastra	76°51'-76°57' E, 20°31'- 20°34' N	636
4.	Jonainala, Keonjhar, Orrisa	85°40'-85°45' E, 21°40'-21°45' N	816
5.	Udhgamandalam (Ooty), Nilgiris, Tamilnadu	76°38'-76°40' E, 11°21'-11°24' N	638
6.	Pogalur ,Coimbatore, Tamilnadu	77°2'- 77°4' E, 11°12'-11°16' N	491
7.	Mawpun, Umiam, Meghalaya	91°54'-91°57' E, 25°40'-25°43' N	800
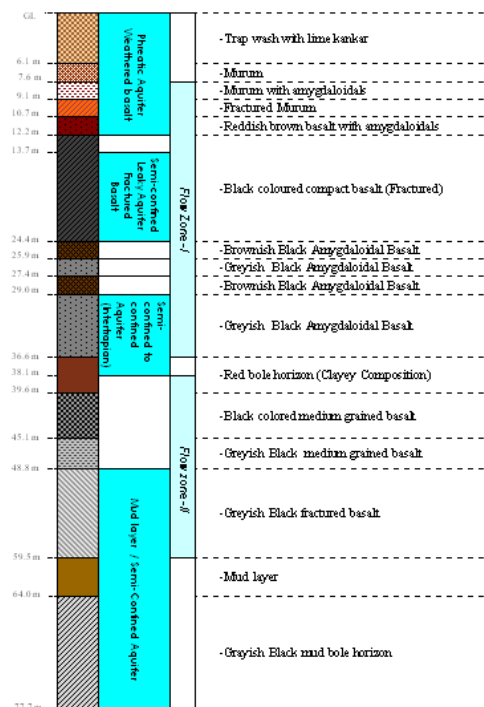
Fig. 2 .Well log data of the representative site of Antisar watershed (Gujrat)

Fig.1. DEM of Study Watersheds

Table: 1. Detailed Required Data of the Study Watersheds

Particulars	Name of the Watersheds						
1. Land use area (ha)	Almus, Tehri Garhwal	Belura, Maharashtra	Pogalur, Coimbatore	Jonainala, Orissa	Udhagaman-dalam, TamilNadu	Umiam, Meghalaya	Antisar, Kheda,Gujrat
a. Irrigated agriculture	6.32	-	130.2	-	-	-	19.56
b. Partially irrigated agriculture	38.61	-	-	-	-	-	
c. Rainfed agriculture	27.43	-	719.6	-	-	-	586.05
d. Agriculture+ tree/ horticulture	2.12	6.95	2.6	30	-	-	
e. Double crop/ terraced cultivation	-	17.92	-	-	-	73.00	16.05
f. Single crop (short +long duration)/ valley rice	-	430.89	-	-	-	57.49	438.37
g. Intercrop/ Shifting cultivation(bun)	-		-	-	-	38.27	131.63
I. Total agricultural area	74.48	455.76	852.4	30	221.89	168.76	1191.66
h. Pine covered land	116.67	-	-	-	-	559.47	-
i. Mixed oak covered land	243.82	-	-	-	-	-	-
j. Moru Oak covered land	121.74	-	-	-	-	-	-
k. Mixed forest cover	-	-	-	180	63.72	136.49	-
l. Eucalyptus grass/ scrub/ acacia	-	-	-	-	86.56	-	-
m. Eucalyptus / bamboo plantation	-	-	-	-	132.08	1.6	-
II. Total Forest land	482.23	-	-	180	282.36	697.56	-

n. Open scrub	58.65	67.70	-	-	9.00	-	-
o. Pasture land	-	-	-	50	20.68	14.17	-
III. Total Grassland	58.65	67.70	-	50	29.68	14.17	-
IV. Land slide/ eroded/ quarry	9.64	-	-	-	-	1.00	-
V Barren/ Fallow/ wasteland	-	52.99	156.1	30.0	-	15.64	113.42
VI. Total Wasteland	9.64	52.99	156.1	30.0	-	16.64	113.42
VII. Habitation	3.16	0.55	11.5	-	8.55	26.44	-
VIII. Grassy swamp / Pond	-	-	-	-	11.71	4.30	-
IX. Tea	-	-	-	-	79.07	-	-
X.Grand Total (I+II+III+IV+V+ VI +VII+VIII+IX+)	628.16	576.45	1020.0	290.0	633.26	927.9	1305.08
2. Soil Characteristics	-	-	-	-	-		
a. Texture	Sil to Sicl	Black cotton, shrink –swell soils	Sandy to clay	Sandy loam to Silty loam	Silty Clay loam to Clay loam	Silt, Silty loam to Silty clay loam	Sandy Clay loam to Clay
b .Genesis	Limestone, Quartzite and Phyllite	Basaltic	-	-	Charnockites	Metamorphic Rock,	Alluvium
c. Type of 'series' of soil found	'Mona' - shallow to very shallow;	Belura (Kd)- Very fine, Ustorthents	Two soil classes – Grsl-d3-D-e2 and Grls-d1-D-e3	Dhaobasi, Belposhi and Udgarsahi	Ootacamund series I, II, and III.	UMIAM (U); SHIPRA (Si); MAWPEN	
d. pH	5.9 to 7.7	-	6.67 to 8.13	-	4.27 to 4.88	-	6.4 to 9.3
e. EC (mmhos/cm	0.324	-	0.1 to 0.2	-	-	-	0.08-0.56
f. Land Capability class	VIIes, VIes, IVw	IIe and III e	III	Work under progress	II, III,IV, V, VI, VIII		
3. Climate							
a. Temp ranges	0 to 22-24	19.15 to 34.18	13 to 39	-	8.5 to 22.1	Avg = 28	10 to 42

(minimum and maximum 0C)							
b. Annual Rainfall (mm)	1500	824.7	602	1300	1180	2399.8	834
c. Type	Temperate to sub-tropical	Sub-tropical Monsoonic	Semi-arid Subtropical Monsoonic	Sub-humid – Sub-tropical	-	Humid, sub-tropical	Semiari d
4. Demography							
a. Total Population	111(families)	842	3000	NA	2232	1598	2104
b. Average size of family	7	6-7	-	NA	-	-	4
c. Sex ratio (female per 1000 male)	945		-	NA	-	1035	
d. Literacy level	Females illiterate, Male (Class IV/V th std)	35 %	50 %	NA	55 %	50%	86%
e. Occupation	Agriculture, followed by Migrant workers	Agriculture, Followed by Carpentry and Blacksmithy	Agriculture followed by Laborers and Service	NA	Agriculture followed by Artisans and service/busines s	Bun cultivation followed by daily wage earners, mining and quarrying, fishing	Agricult ure followe d by landless labourer s

A. Assessment of impact, adaptation and mitigation of climate change on major crops of Bihar

(a) **Trend Analysis of Agro-meteorological variables**: Rainfall, temperature and potential evapotranspiration (PET) are investigated for studying the significant features of climatic variability at three centres viz. Sabour, Pusa and Patna of Bihar in Eastern India. These centres are present in Zone III B, Zone I, and Zone III A of Bihar. Annual, seasonal and monthly rainfall, temperature and potential evapotranspiration (PET) were analyzed by using M-K Test, SP Rho test and linear regression test. The results of trend analysis of different agro- meteorological variables are summarized below:

Monthly Trend: At Sabour, monthly rainfall showed an increasing trend but significant increase at 5 percent is observed during the month of April only. As temperature (maximum and minimum temperature) is concerned, it also shows increasing trend in all of the months except during January and April- June month. However, for most of the months PET shows a downward trend. At Pusa**,** rainfall show upward trend in most of the months but significant increase in rainfall is observed for April, November and December months. A significant increase in minimum temperature is observed for all of the months except March and June. Six out of twelve months show a downward trend in maximum temperature and, significant decrease during January and March is observed. PET follows the same trend as maximum temperature but shows significant decrease during January and significant increase during August month as shown in table 1. In Patna, a decrease in maximum temperature from January to July and in minimum temperature from April to October is observed. However, this decrease in maximum temperature is significant during January and May months and significant decrease during April, July and September in minimum temperature is observed. Majority of months show increase in rainfall and PET for Patna.

Seasonal Trend: Seasonal rainfall shows an increasing trend during all of the seasons however, significant increase during summer and monsoon season at Sabour. Maximum temperature showed decreasing trend during winter and summer season but increasing trend in other two seasons. Minimum temperature showed an increasing trend except during summers. Monsoon and post-monsoon seasons show increased PET. At Pusa**,** rainfall showed downward trend during post-monsoon period and minimum temperature shows significant increase during all the four seasons. However, maximum temperature increased in monsoon and post monsoon seasons. At Patna, on seasonal basis, temperature showed decreasing trend during winter, summer and monsoon season except significant increase in minimum temperature during winter season (December, January and February). An increase in maximum as well as minimum temperature is observed during post –monsoon period. Rainfall showed decreasing trend during summer and post-monsoon period but increased during other two seasons. Potential evapotranspiration however showed an increasing trend for summer and monsoon season but downward trend during winter and post –monsoon**.**

Annual trend: Annual rainfall shows an increasing trend for all of the stations. Maximum as well as minimum temperature showed an upward trend at Sabour. At Pusa

and Patna minimum temperature showed an upward trend but maximum temperature showed a downward trend and this decrease is significant at Patna.

Table 1. Trend in rainfall (RF), maximum temperature (MAXT), minimum temperature (MINT) and potential evapotranspiration (PET) for Pusa (44years)

Months	RF			MAXT			MINT			PET		
	M-K*	SP*	LR*	M-K	SP	LR	M-K	SP	LR	M-K	SP	LR
Jan	D	D	D	D**	D**	D**	I**	I**	I**	D**	D**	D**
Feb	I	I	I	D	D	D	I*	I*	I*	D	D	D
Mar	D	D	D	D*	D*	D	I	I	I	D	D	D
Apr	I	I*	I	D	D	D	I*	I*	I	D	D	D
May	I	I	I	D	D	D	I*	I**	I*	D	D	D
Jun	I	I	I	D	D	D	I	I	I	D	D	D
Jul	I	I	I	I	I	I	I*	I**	I	I	I	I
Aug	I	I	I	I*	I*	I	I**	I**	I*	I**	I**	I**
Sep	D	D	D	I	I	I	I	I*	I	I	I	I
Oct	D	D	D	I	I	I	I*	I*	I	I	I	I
Nov	I	I*	I	I**	I**	I**	I**	I**	I**	I	I	I
Dec	I	I*	I	I	I	I	I**	I**	I**	I	I	I
DJF	I	I	I	D*	D*	D*	I**	I**	I*	D**	D**	D**
MAM	I	I	I	D	D	D*	I*	I**	I*	D	D	D
JJAS	I	I	I	I	I	I	I	I*	I**	I	I	I*
ON	D	D	D	I*	I*	I*	I**	I**	I*	I	I	I
ANNUAL	I	I	I	D	D	D	I**	I**	I**	D	D	D

* Statistical tests; D- decrease; I-increase

 (b) Crop Modeling to study the impact of climate change on crop yield:

Modeling methodology: Four sites namely Patna, Pusa, Sabour and Madhepura situated in different agroecological regions of Bihar were selected to assess the potential effects of climate change and variability. InfoCrop models for wheat, rice and maize were used and inputs like fertilizers, the type of soil cultivation, sowing date, plant density and irrigation schedules are given according to the management practices of that particular region. Meteorological inputs in this model are represented by the daily data as: maximum and minimum air temperature ($^{\circ}$C), solar radiation (KJ m^{-2}day^{-1}), vapour pressure, wind velocity and precipitation (mm). Pedological inputs include physical and chemical charactistics of the soil of selected location.

Modeling crop response to changing climatic scenarios: The crop, meteorological and soil data for selected centers are collected from BAC, Sabour (Bhagalpur), IARI, Pusa, TDC, Dholi (Muzaffarpur), IRS, Madhepura, RAU, Pusa and State Department of Agriculture. InfoCrop, a dynamic process growth model is validated and calibrated for Pusa (85.78°E longitude and 25.85°N latitude) and Sabour (87.17°E longitude and

25.33°N latitude) for wheat, rice and maize crops. Input data for model simulation is fixed and consecutively parameterized to the model required form. The grain yield is simulated by the model and simulated yields are compared with observed yields (Table 2) having a coefficient of efficiency above 90% for all crops and locations. The coefficient of efficiency is calculated based on the model adopted from Kenneth *et al*., 2003*

$$E = 1.0 - \left(\frac{\sum\limits_{i=1}^{N}(O_i - P_i)^2}{\sum\limits_{i=1}^{N}(O_i - \overline{O})^2} \right)$$

Table 2. Observed versus simulated grain yield of maize in Pusa

Year	Observed yield (kg/ha)	Simulated yield(kg/ha)
1998	3620	3622
1999	3560	3452
2000	3010	2900

Coefficient of efficiency (E) =0.93

After validating INFOCROP model for maize, wheat and rice crops, the simulated grain yield is taken. The scenarios are constructed on the basis of the available historical weather data, first the baseline is prepared from the historical weather data (30years data) and GCM predictions (HADCM3) for A2 scenario are then incorporated into the baseline by interpolation method. Maize yield shows an increase for Pusa to the tune of 13%, 17 % and 38 % for 2020, 2050and 2080 respectively when compared with baseline. Although when compared with the yield of maize for the year 2000, the increase in yield was observed to be 23%, 27% and 50% for 2020,2050 and 2080 respectively. A decreasing trend for both rice and wheat yield is observed for the future scenarios. For Pusa, the percentage reduction in wheat yield is upto 25% and for Sabour it is more than 50% towards 2080. When compared with baseline, however the reduction percentage in rice yield is less i.e upto 37% and15% for Pusa and Sabour respectively.
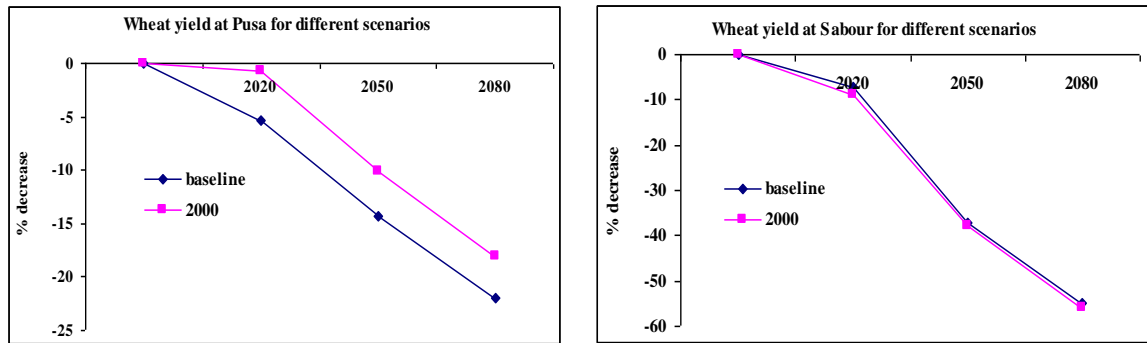
Fig 1. Wheat yield for 2020, 2050 and 2080 at Pusa and Sabour

Sensitivity analysis: The sensitivity analysis for rice, wheat and maize for Pusa area was done in order to reveal the role of projected changes in temperature and effect of increased CO_2 on potential yields (changes are imposed in the observed weather). Temperature (maximum, minimum and both maximum & minimum) was increased from (1 to 4°C) combined with 370 ppm CO_2 and 682 ppm CO_2 concentration. Simulated yield is taken by increasing temperature at both levels of CO_2. At current level of CO_2, increasing maximum, minimum and mean temperature results in decline of estimated rice yield however, this decrease is more prominent with increasing maximum and mean temperature as compared to minimum temperature which shows slight decrease in yield with increasing temperature presented in figure 2(a). Similar trends for wheat could be observed as evident from the figure 2(b). In case of maize increasing the mean and maximum temperature results in decreasing the estimated yield, but increasing the minimum temperature proves to be beneficial up to a rise of 3°C as in figure 2(c). At elevated CO_2, all the crops show an increase in yield with similar trend as observed at current levels of CO_2.
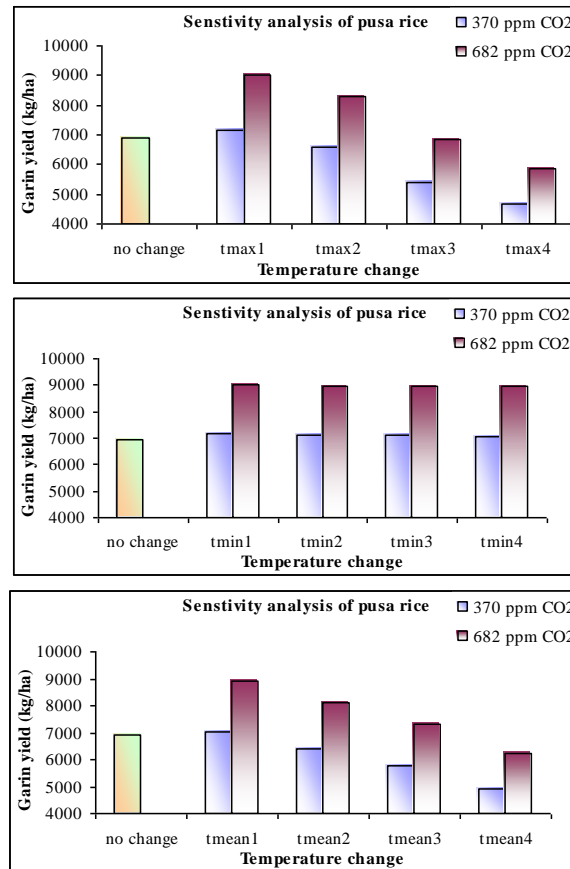
Fig 2(a). Sensitivity analysis for rice crop in response to changing temperature at Pusa
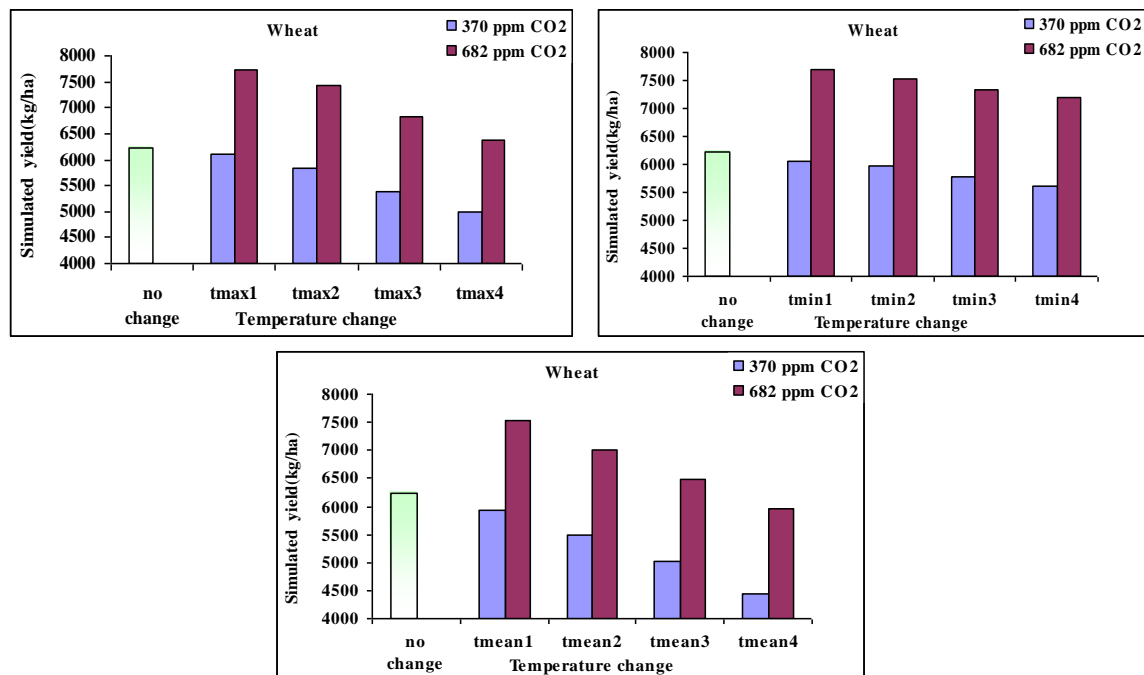
Fig 2(b). **Sensitivity analysis for wheat crop in response to changing temperature at Pusa**
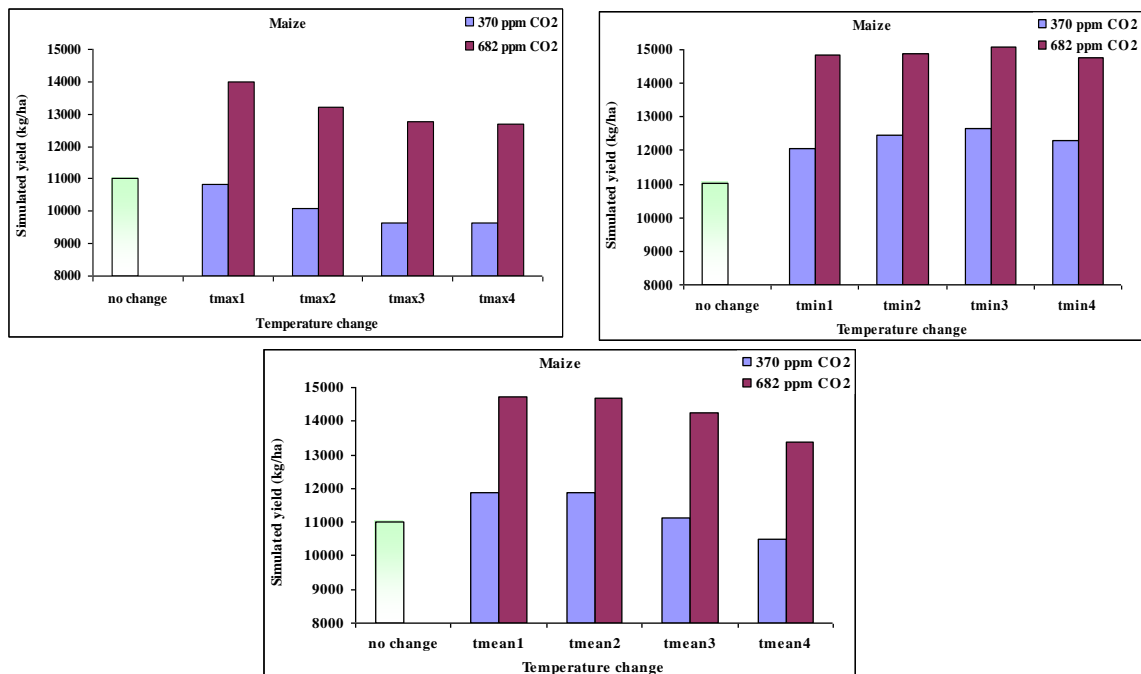
Fig 2(c). Sensitivity analysis for maize crop in response to changing temperature at Pusa

B. Climate change impact assessment on water resource availability for developing
   suitable water management strategy under projected climate change

Hydrological Modeling for Assessing Climate Change Impact in Bhavani Basin

In the second phase of the ICAR Network project on climate change "Impact, Adaptation
and Vulnerability of Indian Agriculture to climate Change", the Upper Bhavani basin
lying upstream of the Bhavanisagar Reservoir with the two main rivers the Bhavani and
the Moyar was selected for assessing the climate change impact on hydrology and water
resources availability in the basin. The basin has a total area of 4100 km^2 and is a high
altitude area at the confluence of the eastern and western Ghats with topography that is
undulating in lower plateau and uplands and rugged in western parts. The elevation
ranges from 300 m above msl on the plains to 2600 m above msl on the Nilgiris plateau.
The mean annual precipitation varies from 700 m on the low lands to over 3000m in the
hills. The main part of the basin experiences a humid equatorial climate, although the
lowland plains are sub-humid. Before studying the impact of climate change on water
resources availability in the basin under different climate change scenarios, an attempt
was made to study the trend in stream flow using past historical data. For this purpose,
stream flow data of three gauging stations, namely, Nellithurai, Thengumarahada, and
Savandapur for the period 1978-2005 were collected and analyzed. Four different
statistical tests, namely, linear regression test, Spearman's Rho test, Mann-Kendall test,
and Sen's estimator of slope were employed for the purpose. All the four tests showed
similar trend. Decreasing trend in mean monthly streamflow was observed throughout the
basin in all most all the months except May (in all 3 stations) and Jan (in Savandapur).
However, the decrease is significant during Jul-Oct, and Dec-Jan in Nelluthari, and Oct-
Dec in Savandapur at 5% significance level (Fig. 3). For delineation of basin into
different hydrological response units (HRUs) for distributed hydrological modeling, total
12 toposheets (1:50,000 scale) covering the basin were georeferenced for digitizing.
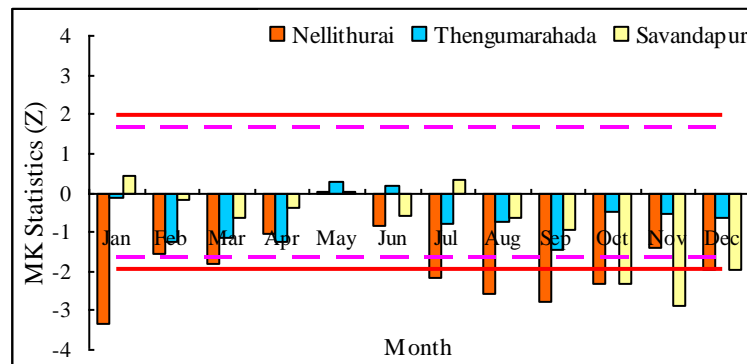
Fig. 3. Mann-Kendall test statistics for streamflow trend in Bhavani basin.

NATIONAL DAIRY RESEARCH INSTITUTE, KARNAL

1.0 Impact of cold wave and wind chill on growth and milk production

1.1 Impact of cold wave

The cold assessed on the basis of outside air temperature doesn't indicate about the true coldness and comfort to enable protection of livestock from winter conditions. Climatic factors like wind speed, relative humidity and sunshine play important roles in determining the intensity of cold outside and comfort in cold. A description of coldness was proposed in the form of "**wind chill index**" to describe the relative discomfort/danger resulting from the combination of wind and temperature. (Siple and Passel Index,1945). Wind chill temperature is a measure of the combined cooling effect of wind and temperature. As wind velocity increases, heat is carried away from the animal body at a faster rate, driving down both the skin temperature and eventually the internal body temperature below their normal temperature and to a state of hypothermia. The Wind Chill Temperature index is thus the measure of this relationship. The Wind Chill Temperature index was computed for Karnal on the basis of air temperature and wind velocity that prevailed during winter of 2006-07, 2007-08. In the present study WCI was used to assess production loss with an assumption that thermal losses from skin of animals are similar to that of man.

During 2007 cold wave swept from Jan 1 to 5 in the North India. Impact of cold wave lashed during January 2007 was analyzed on milk production of cattle and buffaloes. Tmin and wind chill factors were correlated with decline in milk production. The decline in milk production ranged from 1-27% in crossbred cattle. 32.0% cows reduced their milk production by about 5% and 36% cows declined their production in the range of 5-10%, however loss in production of cows was observed between 15-20% in 5.0% cows. About 27% cows did not change their milk production and cold wave effect was not observed in these cows.

During 2008 cold wave in the North India resulted for much longer period than observed during last several years and the cold wave event continued for several weeks. The extended periods, five and fifteen days of the cold wave (Jan 1 –5 and Jan 19-28) when the wind chill factor was low with temperatures 5-7° C below normal near freezing point and wind chill factor less than 2. The milk production losses were more than 20%. One contributing factor to the production losses was the continuous exposure to chilly wind with Wind Chill Index below 0, so there was no opportunity for recovery during daytime (an important element in coping with cold stress). A partly cloud cover and inadequate solar radiation during the day and low to moderate winds speeds were further contributing factors. For cattle and buffaloes in Northern India with low chill factor (ranging from 2 to –2.0) push animals living in open conditions to shiver and to "Emergency" situation, the animal thermal balance is hardly maintained by shivering and increased feed intake. Of the 157 cows monitored for production changes during cold wave of 2008, 49% cows declined their production about 5% and in 28% cows loss in

production was between 5-10% and more than 5.0% declined their production between 10-15% and 18% animals did not exhibit a decline or observed to increase in milk production (Table1).

Low environmental temperatures and lack of prior conditioning result in to low production and death of livestock managed in unprotected or open or partially protected buildings. Cold wave with high wind velocity can push vulnerable animals beyond their survival threshold limits of low temperature. The consequences of exposure to cold could be severe particularly in Indian animals not adapted to severe cold with high wind velocity. The importance of the wind chill index in context of livestock production is that it can help in reducing impact of winter weather. In managing livestock in cold weather an important factor that need to be kept in mind is that surrounding hot air and body heat produced by animals may be used to protect against the cold. Covering of animals with loose, lightweight and warm jute materials (gunny bags clothing) can help in protection and excessive heat loss from body. Tightly- woven and water-repellant outer covers can further protect them from wet winters and wind chill effects.

1.2 Impact of Heat waves

High ambient temperatures during summers can result in production and death losses for un adapted livestock. High temperatures with high wind velocity (Heat waves) cause losses to vulnerable cattle and buffaloes. Continuous exposure of animals, at THI higher than 75, during the heat waves decrease opportunity for recovery at night. Low temperature during night is an important element in coping with heat stress. High temperature accompanying with high solar radiation loads, on clear skies days and low to moderate wind speeds further contribute to risk.

Heat wave during summer negatively impacted milk yield of cattle and buffaloes. On an average loss in production occurred by more than 3.0% accounting 650 lit during 30 days June period. The loss in production due to heat waves on length of lactation has not been considered as some of the buffaloes are impacted in the form of lactation length and reproductive functions. The impact of heat wave was observed to be more on the milk yield of heifers than other cows and buffaloes with an average yield decline of 3.2%. The impact of heat wave during summer on milk yield and production of cows and heifers ranged from 2- 15 %. Heifers and cows were equally sensitive to thermal stress and heat waves swept during June. On an average a decline of 2.5% in milk production of cows occurred and caused a loss of 3200 lit during June.

(Table2)

High ambient temperatures cause production losses in livestock. Temperature rise from January to March have a positive impact on milk yield and increase production of cattle and buffaloes. But temperature rise from March to June reduce yield and production. Heat waves that occur during April to June with ambient temperature above 38- 40 ° C severely impact animal health and productivity. Heat waves in the months of May and June in Northern India, ranging from few days to several weeks, with temperature extremes of 45 °C and wind velocity of 7-8 Km/h negatively impact milk production to about 20-30%. High solar radiation during the day further causes thermal stress. During summer, particularly in May and June months hourly THI values exceeded more than 80

during the day and night. After onset of monsoon in July, air humidity increases and low difference in dry and wet bulb temperatures reduces efficiency of evaporative cooling. Since livestock production system in India is based on small and marginal farmers the production losses during summers and during heat waves could be more in terms of yield per day, health and well being than the organized farms where the heat mitigating measures could be adopted. Heat wave impact assessment studies on milk production of cattle indicate low to moderate loss in yield and production of both cattle and buffaloes. Inadequate protection during heat waves and lack of water availability to livestock often result in production loss and cause health problem in young and unconditioned livestock.

1.3 Feed Intake and growth

Cold exposure of animals also influence feed intake of animals. Feed intake of animals increase during winter months as compared to comfortable months (March and October) and increase in growing animals is higher than adult animals. A sudden drop in temperature during cold wave was observed to reduce their feed intake and Zebu, crossbreds and buffaloes were uncomfortable under open housing system particularly from 5 PM to 9 AM indicating that animals experience cold during night hours. Some of the animals were observed to shiver during early morning that continued till rise of ambient temperature to 15 ° C.

High ambient temperature of May and June depress feed intake and growth rate of animals as compared to comfortable conditions. Dry matter intake decline with rise in THI has been presented graphically (Fig2)

1.4 Impact of temperature on energy expenditure and pulmonary functions

Energy expenditure and methane emissions from cattle and buffaloes were assessed after exposing animals to different temperatures in climatic chamber. The expired air was collected in Douglas bags from individual animal. Volume of air was measured by passing through Wet test meter and analyzed for O_2, CO_2 and methane. The RQ was computed after STPD correction and energy expenditure was calculated. Methane emissions were measured in exhausted air from methane content change and airflow rate.

Exposure of cattle and buffaloes increased their metabolic rate and ventilation volume. The impact of temperature was observed to be more at 35° C than that observed at 40° C indicating that animal response to temperatures are variable. At 32° C heat production increased marginally but at 35° C the response was much more pronounced. Exposure of cattle and buffaloes increased pulmonary ventilation volume of animals and CO_2 content in expired air increased, CO_2 increment declined and O_2 retained increased (Table3 &4). Methane emissions in expired air varied from 0.03 to 0.11% and no temperature effects were noticed on methane emissions. The results indicate that temperature rise impacts animal metabolism and affects pulmonary activity. The rise in respiratory frequency at high temperature impacts CO_2 content of expired air and oxygen uptake of animals.

2.0 THI variations at Karnal

Increase in THI due to temperature rise affects animal growth and productivity but animals are able to dissipate body heat because of higher difference in dry bulb and wet bulb temperature. Dry heat waves often referred as "loo" during May and June reduce productivity but difference in night and day temperatures (10-12 ° C) help in alleviation of thermal loads. The situation changes with onset of monsoon or due to storms or other weather changes. A low difference between T db and T wb decreases efficiency of evaporative cooling and increases animal discomfort.

Air temperature variations occurring every 10 min were recorded at Karnal on a meteorological station. THI for Karnal data based on hourly air temperature and relative humidity records were analyzed and results have presented in **Fig. 3.** The data revealed that THI levels are below 70 throughout the day and night of January and February. The night time temperature are low thus THI were <65 during major part of January and February. During March day temperature increase elevated THI and daytime THI increased to70- 80 particularly in the afternoon. In April THI exceeded 80 during afternoon for 2-3 hours period. Low ambient temperature during night (T min) permit heat dissipation from skin and animals dissipate heat gained during night at low THI. But in May the values of THI exceed 80 for 83.5% of the 24h period and for more than 4-6 hours animals were in distress with THI higher than 85. During May and June 45-50% of the daytime THI was more than 85 thus animals were under severe stress and gained heat from environment. Increase in air humidity with onset of monsoon caused a rise in THI and animals were uncomfortable mainly due to decline in difference in temperature. In the months of July and August hourly THI values were higher than 75 and more than 45% of the time temperature humidity conditions were distressful and THI values were >85. Ambient temperature started declining from September onwards and animals were comfortable and their productivity improved.

In order to estimate duration of uncomfort during different days of the year and variations THI were computed from hourly records of dry bulb and humidity for the twelve months and summer period of April to June and rainy season of July to September. The analysis revealed that THI starts increasing in afternoon from Feb onwards and exceed 75 for 2-3 h in the afternoon from March onwards. For more than 1500 h during the year THI ranges between 76-80 and for other 1500 h between 81-85. THI exceeding 85 (86-95) are observed during May for more than 115 h and total number of hours exceeding 86 increases to 300-350 h during July and August. The severe stress days with THI > 85 are predominantly observed from May to August. After onset of monsoon in June/ July difference between morning and evening THI is reduced and animals get limited opportunity for recovery from thermal stress due to higher humidity. During summer months (May and June) THI with a value of 80 or more increase by more than 450% as compared to comfortable March (65 h Vs 295 h). Decline in THI during night in summer months (April and May) due to low temperature during night provide opportunity to animals for heat dissipation.

For crossbred cattle and buffaloes in Northern India and place like Karnal or other places with 20 h or more daily THI-hrs (THI _ 84) for several weeks, the animal heat load is not dissipated that cause economic and health losses. The increased number of days by about 260% from existing 40 to 104 days with a change Tmax and Tmin will further

impact animal thermal balance affecting productivity and health. Under climate change situations the rise in temperature with a decline in precipitation in Punjab, Rajasthan and Tamil Nadu is likely to cause severe impacts on livestock production due to decline in availability of water. The state is already experiencing severe water shortage for intensive agriculture production system. The all-round warming likely to occur in the seasonal mean temperatures and in the extreme temperatures also and both the days and nights higher temperatures in the future will impact animal reproductive cycles and therefore will affect milk yield and production due to decline in difference in Day and night temperature. The night temperatures will be increasing at much higher rates than the day temperatures. The lowest minimum temperatures are expected to be warmer by more than 5°C over most parts of the India; the highest maximum temperatures show an increase of only 2°C. The recent evidence indicates that the minimum temperatures are increasing more rapidly than the maximum temperatures not only over India, but also across several regions in the world.

The projected changes in the T min and T max extremes will affect thermal balance of animals working in field and animals grazing during day time in hot humid conditions in Northern India. The night temperature increase at much higher rates than the day temperatures will not permit animals to dissipate their thermal loads and recovery to normal will be affected.

2.1 THI stress due to climate change during 2080-2100

Analysis of stress on livestock on the basis of THI calculated for different days of the years 2005 and 2006 revealed that for 160-165 days THI was less than 65 in northern India and for about 50 days the THI ranged between 66-70. THI was more than 70 for about 40-42 days and THI ranged between 75 and 80 for 95-100 days during the year. The uncomfortable THI (>80) due to high temperature are observed for about 40 days.

The results further indicated that the congenial THI for production are only about 40 % and more than 30 percent of time the THI exceed 80 and 13% of the days with THI> 85 are distressful to livestock production (Fig 4). The temperature rise as per HADCM3 projections is likely to increase uncomfortable days with THI>80 from existing 40 days (10.9%) to 104 days (28.5%) for A2 scenario and 89 days for B2 scenario for time slices 2080-2100. the results further indicate that number of days with THI >80 will increase by 260 % causing severe economic loss to farmers.

3.0 Identification and calibration of NRC model for suitability in Indian dairy animals incorporating changes in temperature and feed intake

NRC model has been widely used for calculating nutrient requirements of livestock. Though suitability of NRC model for livestock of India has limitedly been investigated, an attempt has been made to assess suitability of NRC standards for cattle with emphasis on compensation for temperature changes. The requirements for energy and protein increase with change in temperature.

Energy requirements for maintenance as per NRC, 2001 is : 0.080 Mcal/kg BW 0.75

Energy requirements for maintenance as per NRC, 1976 is : 129 kcal/kg BW 0.75

Energy requirements for maintenance as per Kearl: 118 Kcal/Kg BW 0.75

Mild to severe heat stress has been observed to increase maintenance requirements by 7-25% that is equal to 0.7 to 2.4 Mcal/day.

NRC standards take into account high metabolic activity and requirements for milk production of temperate breeds of cattle. The requirements of Zebu and crossbreds cattle are lower than NRC and have been observed to be different (Kearl, 1982). We have considered both of these and observed that nutrient requirements as per NRC are 27-30% higher than Kearl or actual requirements due to their metabolic activity at lower level and low heat expenditure per unit surface area. The energy expanded by Indian cattle and buffaloes under stressful conditions based on NRC, therefore are likely to be unrealistic. The work is in progress on the measurements and likely to provide information suitable for use in CC impact studies.

4.0 Suitability of various thermal alleviating measures

The suitability of alleviating measures was assessed during different months of summer and rainy seasons. Cooling efficiency was computed from dry and wet bulb differences.

The impact of heat stress on production of crossbred cattle and buffaloes has limitedly been evaluated. Recently efforts have been made to alleviate heat stress of cows using heat abatement system such as shades, fans, fog misters, and sprinklers. These systems differ in efficacy of cooling and thus create variation in thermal conditions to which animals are exposed. Thermal relief provided by these devices differs significantly at different places and have not been evaluated. Climatic conditions in the Northern India from March to June (Summer) are characterized by high air temperature and dry air. During rainy season from July to September high temperature is associated with high humidity. These hot and humid conditions particularly after monsoon onset significantly compromise evaporative heat loss from animals. The evaporative cooling of cows is more successful from April to June when dry bulb temperature is high and humidity levels are low compared to July to September when humidity levels are more with temperature.

Methodology

The temperature difference between the T db and T wb is referred as Wet bulb depression indicates the maximum decrease of air temperature by evaporation. The wet bulb depression helps in prediction of evaporative cooling on the basis of decline in temperature. The cooling power of air is related to wet bulb temperature and evaporative efficiency. Evaporative efficiency is the reduction in dry bulb temperature as a percentage of the difference between the dry bulb temperature and the wet bulb temperature. Assuming efficiency of the evaporative cooling system (60,70 and 80%), the temperature of the cooled air has been calculated and presented below:

A 70% efficient evaporative cooling system at Tdb = 35°C and Twb = 24°C can cool the air to 27.3°C. At the same environmental conditions, but with a 60% and 80% efficient evaporative cooling system, the temperature will be reduced to 28.4 and 26.2°C, respectively.

Tcool = Tdb − eff × (Tdb − Twb).

4.1 Adiabatic cooling efficiency in India

Average monthly pattern of temperature-humidity index (THI) during morning and evening as indicated earlier indicates that THI during morning is lower than afternoon mainly due to rise in ambient temperature during summer. Evaporative coolers are usually turned on when Tdb ε 35°C (95°F), which usually occurs in mid April to early May at Karnal. Considering this fact and assuming that an evaporative cooling system with efficiency of 70% is used, THI in April/May is reduced to near 70, which is below the threshold of heat stress. This may help in reducing impact of temperature rise on milk yield of sensitive livestock in tropical conditions.

Table 1 Efficiency of cooling during different months at Karnal, Haryana, India

	Tdb	AvDWB		Cooling	
			60%	70%	80%
Months					
Jan	17.76	3.60	15.60	15.24	14.88
Feb	20.48	4.63	17.70	17.24	16.77
Mar	27.77	7.80	23.09	22.31	21.53
Apr	35.06	14.55	26.33	24.87	23.42
May	36.90	14.50	28.20	26.75	25.30
Jun	37.63	12.10	30.37	29.16	27.95
Jul	31.97	4.50	29.28	28.83	28.38
Aug	33.87	5.85	30.37	29.78	29.20
Sep	30.99	4.97	28.01	27.51	27.01
Oct	31.38	9.27	25.83	24.90	23.97
Nov	27.20	10.48	20.92	19.87	18.82
Dec	20.91	6.93	16.75	16.06	15.37

Efforts have been made to alleviate heat stress of cows using heat abatement system such as shades, fans, fog misters, and sprinklers. These systems differ in efficacy of cooling and thus create variation in thermal conditions to which animals are exposed. Thermal relief provided by these devices differs significantly at different places in relation to depression in wet bulb temperature and have not been evaluated for different places in India. Efficiency of cooling has been calculated for different places based on WBD during different months. Places have been identified for evaporative cooling that may help in reducing thermal stress of livestock by using evaporative coolers. The use of heat abatement system such as foggers or coolers can help in reducing livestock production loss by reducing THI to 70 or less from 80-85. The places and months of year when heat-alleviating system may be applied have been presented below in table

Table.2 Depression in Wet bulb temperature (DWB) at selected places in India during summer

Place	Months	DWB (°C)
Jhansi, UP	March -June	10- 15
Ahmadabad,Gujrat	March- June	10- 17
Indore,MP	March- June	10-17
Hissar, Haryana	March-June	10-15
Kota, Raj.	March-June	10-18
Bidar, Karnatka	March-June	8-14
Mysore	March-April	10-14
Nagpur	March-June	10-17
Mainpuri, UP	March-June	12-17
Jodhpur,Raj	March-June	12-18
Nimach	March-June	10-15
Panchmarhi	March-May	12-15
Surat	Feb- May	8-12
Poona	March-May	8-12
Kurnool	March-May	12-15
Raichur, Karnatka	March- June	10- 14
Meerut, UP	March-June	10-15
Udaipur	March-June	12-15
Parbhani	March-June	12-16
Karnal	March -June	10-15

4.2 Use of fans in livestock buildings

During the months of July to September heat loss to environment declines due to increase of air humidity and low gradient for heat loss to air. The difference between dry and wet bulb is less than 5 °C and T db is near 35°C. Low air velocity of 2-3 km /h is unable to dissipate body heat and animals are under distress. During these months THI for 24 h are in the range of 80-90. Adiabatic cooling becomes in effective and normal ceiling fan on livestock displaces air far less than that is required for maintaining body heat balance. High velocity blast fans (large and medium size) and mounted on sidewalls are able to reduce body temperature of animals within physiological limits of about 1°C of normal. The devices like fans and foggers fitted with timers can help in maintaining humidity and temperature in closed animal houses and help in heat loss by enhancing evaporation from skin of crossbred cattle and buffaloes.

5.0 Integration of market economics in the assessment of mitigation of enteric methane mitigation option: case of dynamic milk region of Haryana

The economic framework is used to estimate the effects of exogenous changes in human population, real income, animal productivity and feeding cost of dairy animals on milk production and consumption, milk prices and the number of dairy cattle required to satisfy the demand for milk. The enteric methane emission factors are then used to determine the change in methane emissions as a result of introducing the strategic supplementation for reduction of enteric methane. In this analysis the levels of milk production and number of dairy animals are determined endogenously, within the economic framework, rather than treated as exogenous parameters that one must forecast by other methods

5.1 Brief Background: Most existing studies of enteric methane mitigation options focus on the dietary aspects of the problem and on the translation of changes in diet into changes in methane. The economics of changing livestock diets, if it is treated at all, it is treated from the farm, as opposed to the market, that is, the economic costs and benefits of changing feeding practices are estimated for a typical livestock operation, assuming that changes in input costs and production do not affect market prices for livestock products . As such, economics does not really enter into the projection of future product demand. Instead, the level of future product demand is extrapolated from existing trends in population growth and income, without reference to the possible impact of changes in diet on future market prices. The problem with this approach is that it neglects the effects of changes in feeding practices, directly and indirectly, on future product prices and the inter-relationship between market price, population and income growth and production levels. The approach followed in the present study overcomes this limitation.

5.2 Methodology:
The demand and supply equations of milk are estimated simultaneously using time series data for the state of Haryana for the period 1966/67 -2004/05.
Milk demand = f(wholesale price of milk, population , real income)
Milk supply = f(wholesale price of milk, feed cost)
Milk demand =milk supply

The inverse demand and supply functions from the above estimated equations are integrated to form the benefit function:
Integrating Price of Milk = f(Milk demand, population , real income) wrt milk demand
And integrating
Price of Milk = f(Milk supply, feed cost) wrt milk supply
gives total willingness to pay (TWTP) and production cost (PCost), respectively.
The difference between TWTP and PCost is total surplus.
The base period is taken as 2004. Future projections with and without adoption of methane mitigation options are made for 2020 based on the assumptions enumerated later.

5.3 Summary of findings:

Scenario A

The results of analysis have been presented in table
Adoption of enteric methane mitigation option (supplementation of MUP) has the potential to increase milk production in 2020 by 2.01% (coverage 25% dairy animals) to 7.53% (coverage 100% dairy animals) in comparison to milk production level in 2020 without application of any mitigation option. Despite of an increase in the annual total production costs of 1.07-3.82% and additional annual investment of say, Rs.50 to 200 million per annum (for providing services and incentives to facilitate adoption and production of feed supplement) the total surplus shall increase by 3.89 to 14.72% compared to BAU scenario. This is because the adoption of mitigation option decreases the equilibrium market price of milk and increases the consumer's surplus (as captured through total willingness to pay).

The resulting productivity increases due to mitigation option also implies lesser stock of dairy animals is required to meet the demand for milk. Lower stock of animals and decline in emission rate per head translates into 11.4 thousand tones (4.2%) to 45.7 thousand tones (16.8%) reduction in methane emissions from dairy animals. The additional investment of about 3 Euros per tone of CO_2 equivalent methane increases the milk production and total surplus. Also, if carbon-trading benefits can accrue, that will be over and above the gains calculated here.

Table-1 IMPACT OF COLD WAVE ON MILK PRODUCTION OF CATTLES AND BUFFALOES

		Jan-08				
Species		No. of Animals	Total MP	Avg. MP(Kg/day)	Decline in MP/month	Avg loss in %
BUFFALO	Lactating Buffaloes	66	17035	549.5	-337.5	-1.9
	Heifers	21	4976.5	160.5	-217.5	-4.3
CATTLE	Lactating Cows	157	67148.7	2166	-1442.8	-2.1
	Heifers	78	29129.5	939.6	-533.5	-1.8

Table 2   IMPACT OF HEAT WAVE ON MILK PRODUCTION OF CATTLES AND BUFFALOES

		Jun-07				
Species		No. of Animals	Total MP	Total MP (Kg/d)	Decline in MP/month	Avg loss %
BUFFALO	Lactating Buffaloes	111	22377.5	745.9	-650	-2.9
	Heifers	29	6091	203	-193	-3.1
CATTLE	Lactating Cows	320	94221	3140.7	-2414	-2.5
	Heifers	139	31639	1054.6	-788.5	-2.4

Table 3. Effect of environment temperature on oxygen consumption and pulmonary functions of buffaloes

		BUFFALOES	Body Weight = 293.7 Kg	
	Normal environment	BEFORE		
		32 °C / 50% RH	35°C/ 50% RH	40°C/ 50% RH
		Mean ± Standard Error		
O_2	17.9 ± 0.06	18.2 ± 0.05	18.2 ± 0.08	18.3 ± 0.1
CO_2	2.9 ± 0.05	2.8 ± 0.07	2.7 ± 0.08	2.3 ± 0.1
CH_4	0.08% ± 0.02%	0.05% ± 0.01%	0.12% ± 0.0006	0.03% ± 9.4E-05
CO_2 increment	2.8 ± 0.05	2.8 ± 0.07	2.6 ± 0.08	2.3 ± 0.1
O_2 retained	3 ± 0.06	2.7± 0.05	2.8 ± 0.08	2.6 ± 0.1
RQ	0.94 ± 0.02	1 ± 0.01	0.9 ± 0.04	0.9 ± 0.005
VE	1.3 ± .04	1.4 ± 0.04	2 ± 0.04	2 ± 0.05
VE Calculated	30.2 ±1	32.4 ± 0.83	46.9 ± 1	46.7 ±1.1
HP cal/day	6172.5 ± 177.2	6414.2 ± 179.1	8692.1 ± 366.7	8215.6 ± 391.7

Table 4. Effect of environment temperature on Oxygen consumption and pulmonary functions of cattle

		CATTLE		
		BEFORE	Body Weight = 315 Kg	
	Normal environment	32 °C / 50% RH	35°C/ 50% RH	40°C/ 50% RH
		Mean ± Standard Error		
O_2	18 ± 0.08	18 ± 0.06	18.3 ± 0.1	18 ± 0.2
CO_2	2.9 ± 0.06	2.8 ± 0.05	2.6 ± 0.03	2.7 ± 0.2
CH_4	0.06% ± 6E-05	0.05% ± 0.0001	0.18% ± 0.0004	0.03% ± 1.8E-05
CO_2 increment	2.8 ± 0.06	2.8 ± 0.05	2.6 ± 0.03	2.7 ± 0.2
O_2 retained	2.9 ± 0.08	2.8 ± 0.06	2.6 ± 0.1	3 ± 0.2
RQ	0.9 ± 0.009	1 ± 0.01	1± 0.02	0.9 ± 0.04
VE	1.5 ± 0.06	1.3 ± 0.06		1.8 ± 0.1
VE Calculated	35.2 ± 1.1	30.8 ± 1.4		41.1 ± 2.1
HP cal/day	7714.3 ± 235.8	6223.3 ± 288.6		8641.3 ± 694.9

Table 7. Methane Mitigation options

BAU: Business as usual scenario, that is, no methane mitigation option
Mitigation (100%) and (25%) implies covering 100% and 25% dairy animal population, respectively, with   methane mitigation option

Table 1   Impact of Coldwave on Milk production of Cattles and Buffaloes

		Jan-08				
Species		No. of Animals	Total MP	Avg. MP(Kg/day)	Decline in MP /month	Avg loss in %
BUFFALO	Lactating Buffaloes	66	17035	549.5	-337.5	-1.9
	Heifers	21	4976.5	160.5	-217.5	-4.3
CATTLE	Lactating Cows	157	67148.7	2166	-1442.8	-2.1
	Heifers	78	29129.5	939.6	-533.5	-1.8

Table 1   Impact of Heatwave on Milk production of Cattles and Buffaloes

Species		No. of Animals	Total MP	Total MP (Kg/d)	Decline in MP/month	Avg loss %
		Jun-07				
BUFFALO	Lactating Buffaloes	111	22377.5	745.9	-650	-2.9
	Heifers	29	6091	203	-193	-3.1
CATTLE	Lactating Cows	320	94221	3140.7	-2414	-2.5
	Heifers	139	31639	1054.6	-788.5	-2.4

Table 3. Effect of environment temperature on Oxygen consumption and pulmonary functions of buffaloes

		BUFFALOES		
		BEFORE	Body Weight = 293.7 Kg	
	Normal environment	32 °C / 50% RH	35°C/ 50% RH	40°C/ 50% RH
		Mean ± Standard Error		
O_2	17.9 ± 0.06	18.2 ± 0.05	18.2 ± 0.08	18.3 ± 0.1
CO_2	2.9 ± 0.05	2.8 ± 0.07	2.7 ± 0.08	2.3 ± 0.1
CH_4	0.08% ± 0.02%	0.05% ± 0.01%	0.12% ± 0.0006	0.03% ± 9.4E-05
CO_2 increment	2.8 ± 0.05	2.8 ± 0.07	2.6 ± 0.08	2.3 ± 0.1
O_2 retained	3 ± 0.06	2.7± 0.05	2.8 ± 0.08	2.6 ± 0.1
RQ	0.94 ± 0.02	1 ± 0.01	0.9 ± 0.04	0.9 ± 0.005
VE	1.3 ± .04	1.4 ± 0.04	2 ± 0.04	2 ± 0.05
VE Calculated	30.2 ± 1	32.4 ± 0.83	46.9 ± 1	46.7 ±1.1
HP cal/day	6172.5 ± 177.2	6414.2 ± 179.1	8692.1 ± 366.7	8215.6 ± 391.7

Table 4. Effect of environment temperature on Oxygen consumption and pulmonary functions of cattle

		CATTLE		
		BEFORE	Body Weight = 315 Kg	
	Normal environment	32 °C / 50% RH	35°C/ 50% RH	40°C/ 50% RH
		Mean ± Standard Error		
O_2	18 ± 0.08	18 ± 0.06	18.3 ± 0.1	18 ± 0.2
CO_2	2.9 ± 0.06	2.8 ± 0.05	2.6 ± 0.03	2.7 ± 0.2
CH_4	0.06% ± 6E-05	0.05% ± 0.0001	0.18% ± 0.0004	0.03% ± 1.8E-05
CO_2 increment	2.8 ± 0.06	2.8 ± 0.05	2.6 ± 0.03	2.7 ± 0.2
O_2 retained	2.9 ± 0.08	2.8 ± 0.06	2.6 ± 0.1	3 ± 0.2
RQ	0.9 ± 0.009	1 ± 0.01	1± 0.02	0.9 ± 0.04
VE	1.5 ± 0.06	1.3 ± 0.06		1.8 ± 0.1
VE Calculated	35.2 ± 1.1	30.8 ± 1.4		41.1 ± 2.1
HP cal/da	7714.3 ± 235.8	6223.3 ± 288.6		8641.3 ± 694.9

Table 7. **Methane Mitigation options**

		2004	2020			2020	
		Base case	BAU	Mitigation (100%)	Mitigation (25%)	BAU	Mitigation (100%)
			Scenario A	Scenario A	Scenario A	Scenario B	Scenario B
Milk production/ consumption	million tonnes/yr	5.299	7.873	8.466	8.031	5.806	6.670
Per capita milk consumption	gms./day	645	744	800	759	549	630
Domestic milk price	Rs./lit.	18.40	33.06	32.60	32.93	36.27	35.60
TWTP	Rs. billion/year	114.04	292.76	312.89	298.16	229.95	261.94
Production Cost	Rs. billion/year	76.65	212.61	220.74	214.89	185.07	203.55
Investment	Rs. billion/year	0	0	0.2	0.05	0	0.75
Total Surplus	Rs. billion/year	37.38	80.15	91.95	83.27	44.88	57.64
Economic cost	Rs. billion/year	76.65	212.61	220.94	214.89	185.07	204.30
Dairy animals	thousands	3341	4136	4047	4116	2864	2988
buffaloes	thousands	2771	3438	3364	3422	2505	2614
crossbred cows	thousands	268	394	385	392	240	250
local cows	thousands	302	304	298	303	119	124
Total Methane emissions	tonnes/year	216500	271533	225833	260098	192553	170795

BAU: Business as usual scenario, that is, no methane mitigation option
Mitigation (100%) and (25%) implies covering 100% and 25% dairy animal population, respectively, with   methane mitigation option
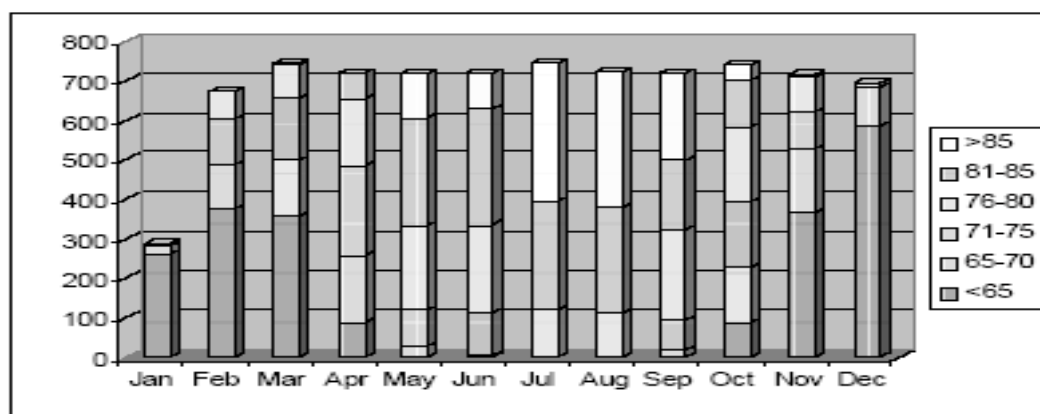
Fig 2. Distribution of Temperature Humidity Index during different months at Karnal
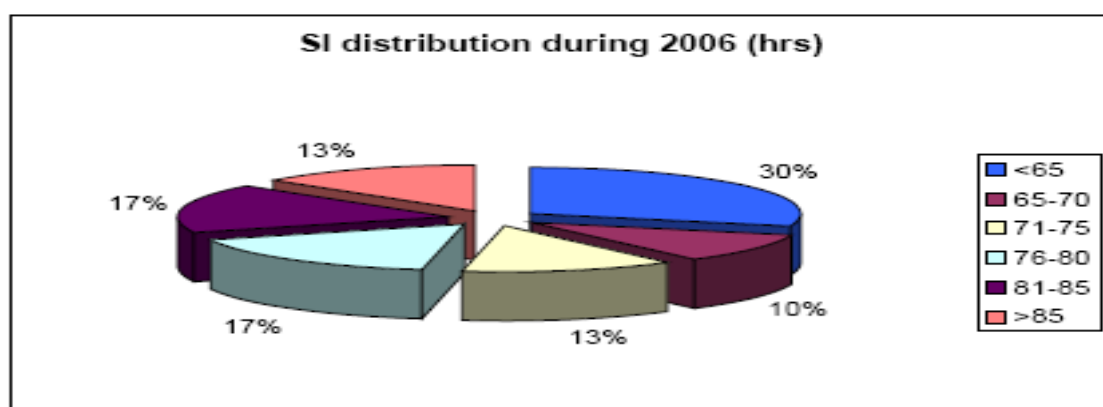
Fig 3. Distribution of THI hours

Objective 1. To assess the adaptability and vulnerability of marine organisms

In Phase I, it was detected that the oil sardine has adapted to seawater warming by extending its distributional range to northern latitudes in the last 20 years. Similar strategy by another dominant and commercially important fish, the Indian mackerel, has been noticed.

The Indian mackerel *Rastrelliger kanagurta* is able to adapt to rise in sea surface temperature by extending distribution towards northern latitudes; and by descending to depths.Indian mackerel, *Rastrelliger kanagurta is* one of the commercially important pelagic fish. It is a tropical fish, distributed in 30°N - 24°S, 30°E-180°E and prefers seawater temperature of 27°C or more. It generally occupies surface and subsurface waters. The annual production of mackerel in India is about 1.4 lakh tonnes (5% of the total marine fish production) and has a total value of about Rs 350 crores. It has a crucial role in marine ecosystems as a plankton feeder and as food for larger fishes and also a staple sustenance and nutritional food for millions.

During 1961-76, the mackerel catch along the northwest coast of India contributed about 7.5% to the all India mackerel catch, which increased to 18% during 1997-06. In the northeast coast, the mackerel catch contributed 0.4% to the all India mackerel catch during 1961-76, which increased to 1.7% during 1997-06. Similarly along the southeast coast the mackerel catch during 1961-76 was found to be 10.6% of the all the India mackerel catch, which increased to 23.2% during 1997-06. Along the southwest coast, the mackerel catch contributed about 81.3% to the all India mackerel catch during 1961-76, which decreased to 56.1% during 1997-06. A good correlation between sea surface temperature, chlorophyll concentration and mackerel catch was discernable.

The mackerel was conventionally caught by surface drift gillnets by artisanal fishermen. In recent years, however, the fish is increasingly getting caught in bottom trawlnets operated by large mechanized boats at about 50 m depth. In 1985, only 2% of the total mackerel catch was from bottom trawlers. In the last five years, about 10% of the mackerel catch is by the bottom trawlers (Fig. 1). This shows that the fish descends down to overcome warmer surface waters.
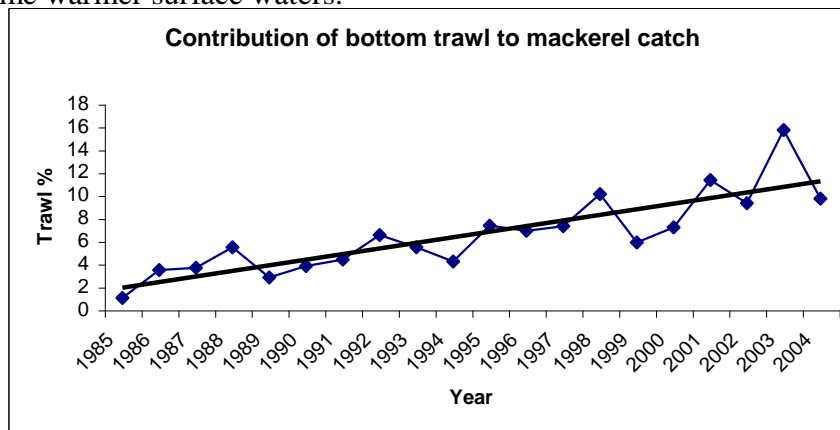
Fig 1. Evidence to show that Indian mackerel is descending down to depths in all the seasons

We attribute that the extension of Indian mackerel towards the northern latitudes is due to the warming up of the surface waters of the Bay of Bengal and Arabian Sea. The distributional shifts of oil sardine and Indian mackerel are expected to result in drastic changes in species mix and ecosystem structures and functions. The changes in species dominance and mix will induce regional adoption of new fishing practices. This will, in turn, impact the economic returns of the fishermen. Considering this, a generalization on adaptability and vulnerability of several other commercially important fish groups (among the remaining 85%) is being attempted by considering regional and seasonal catch and SST, chlorophyll and other oceanographic data.

Objective 2. To assess the impact on primary and secondary producers

Laboratory experiments were initiated to assess the impact of seawater temperature, salinity and pH on the survival and growth of major phytoplankton.

Objective 3. To evaluate socioeconomic conditions of coastal communities in the changed scenarios

Many of the coastal fishing villages are vulnerable to sea level rise as they are located close to the seashore. An inventory on the vulnerability of coastal fishing villages was prepared under this project. To identify the most vulnerable villages, a survey on the distance from high-tide line (HTL) to each fishing village was undertaken.

Number of villages	458 (17.3%)
Population	969255
No. of crafts	
Mechanised	9836
Motorised	18225
Non motorised	17276

Table: 1. Details of fishing villages in India within 100m from seashore

Demographic details and infrastructure available in the fishing villages of maritime states were collected. There are about 2643 fishing villages along the Indian coast, out of which 458 are within 100m (Table 1). The largest number of coastal fishing villages, which are within 100m, are in Kerala (about 200) (Figure 2). The population in the 458 coastal fishing villages is around 1 million (Figure 3).

Figure 2
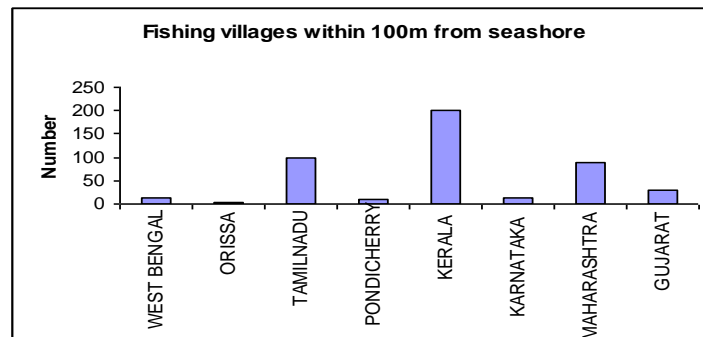
Fishing villages within 100m from seashore
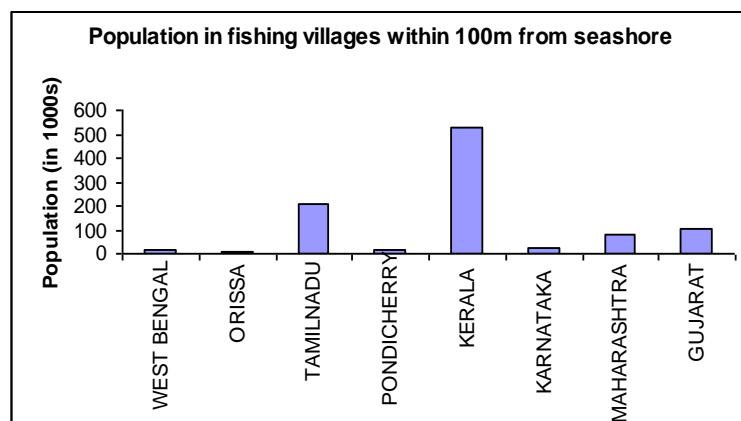
Figure 3

Population in fishing villages within 100m from seashore

The data on vulnerable fishing villages will be helpful for estimating the cost of relocating the villages; and sensitize the fishing communities on the perils of rising sea level.

Objective 4. To evolve adaptation and mitigation measures to sustain Indian marine fisheries

A survey undertaken under this project on diesel consumption by fishing boats in major fishing harbours along the east and west coasts is nearing completion. There are about 58,911 mechanised and 75,591 motorised fishing boats in India. They use diesel for propulsion and fishing.

For the present study, data on the diesel consumption by the mechanized and motorised boats were collected from the major fishing harbours in Cochin, Tamilnadu, Maharashtra and Gujarat. Data were collected from about 1332 mechanised boats and 631 motorised boats in the major fishing harbours. From this, an estimate is being made on the CO_2 emission by the marine fishing boats in India. Initial estimates indicate that fossil fuel consumption by marine fishing boats is around 1200 million liters per year and CO_2 emission by marine fishing sector is around 2.4 million tonnes per year; CO is around 0.2 million tonnes per year.

Initial results indicate that there is scope to reduce the carbon footprint by the marine fishing boats by setting emission norms and improving the fuel efficiency of engines.

CENTRAL INLAND FISHRIES RESEARCH INSTITUTE, BARRAKPORE

Objective 1.

Impact of temperature and rainfall on the breeding of Indian major carps in Fish seed hatcheries of Orissa.

Aquaculture practice of breeding in captivity of fishes viz. Indian major carps, *C. catla, L. rohita* and *C. mrigala* 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, as a result it has been possible to breed them twice in a year at an interval ranging from 30-60 days. It is of significance to note that the climate is showing perceptible changes in India on a regional scale over the years. Temperature is one of the dominant factors influencing the reproductive cycle in fishes. During these 6 months (January to June) temperatures in India gradually increase and reach their maximum by May-June. This environmental factor along with rainfall and photoperiod stimulate the endocrine glands which help in the maturation of gonads of carp. In Orissa the average temperature is on the rise over the last 30years. The average maximum and minimum temperature throughout the state during the time period 1975-2000 has increased by 0.57ºC. and 0.11ºC while the average rainfall has decreased. A perusal of the records reveals that the South West Monsoon comes at the earliest by 26th May and latest by 26th June. If 7th June is taken as the commencement of monsoon; the tendency of monsoon coming late is increasing. Thus the natural phenomenon which decreases the temperature is getting delayed every year. Consequently its impact is being felt in the inland water bodies and on inland fish.

With this background investigation was conducted to ascertain the impact of temperature on the breeding of Indian major carps in the fish hatcheries in four districts of Orissa. The study was having objectives to analyze i) the climatic changes viz. increase in temperature and rainfall pattern some districts of Orissa, ii) impact of elevated temperature on the breeding of Indian major carps and impact on the fishers.

Study Area
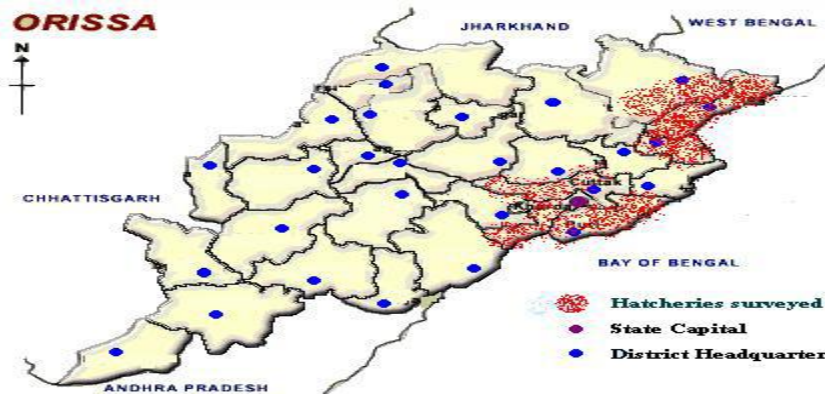
Methodology

Temperature: Annual maximum and minimum air temperature data of the areas covered in survey was collected from IIMT Pune. Mean minimum air temperature during the breeding period of March to September in the last two decades was taken into account in the surveyed fish seed hatchery centres of the districts of Puri, Khurda, Balasore and Mayurbhanj. Analysis of the data was done.

The investigation was carried out in four districts of Orisa viz. Puri, Khurda, Balasore, and Mayurbhanj. The aim of this study was to look into the activities in the fish hatcheries in the above mentioned districts. This period of the year was chosen so as to ascertain the on spot situation during the peak season. Fifty fish seed hatcheries were surveyed in the above-mentioned districts

Impact studies on breeding and fishers: A list of fish seed hatchery owners was prepared based on their performance and sustainability during the last two decades. A list of fishers containing both the hatchery owner as well as the salaried workers was prepared. Two questionnaires (for hatcheries and fisher) were prepared based on the preliminary survey of the hatcheries. The questionnaires were pre-tested and finalized for data collection. A total of 100 fishers from 20 small and large scale hatcheries were interviewed selected at random constituted the study. Data on various parameters in the two time periods; prior to 1990 and 1990-2005 were collected from recorded data available as well as personal interview method. The sample included the operative persons in the hatcheries. The gathered information has been analyzed through simple tabular analysis to cater to the need of the objectives.

Parameters studied were the fish species, brooder management, procedures and techniques in breeding, breeding season (starting time period to ending time period), price and marketing.

Trend of temperature alteration in districts

From the analysis of past data, the following trends were observed for maximum and minimum temperatures in various districts

Khordha

The mean minimum air temperature at Bhubaneshwar in the district of Khordha during the months (March to September) showed an increase by 0.17 °C and mean maximum temperature has increased by 0.11°C.
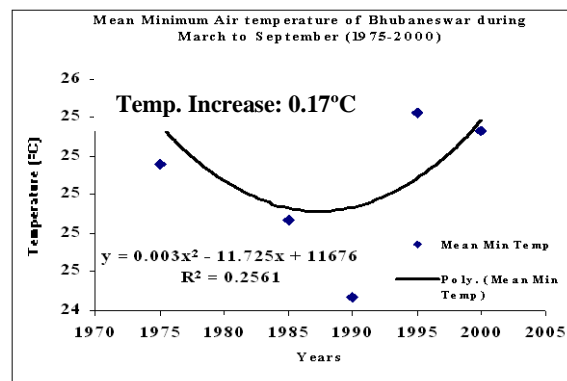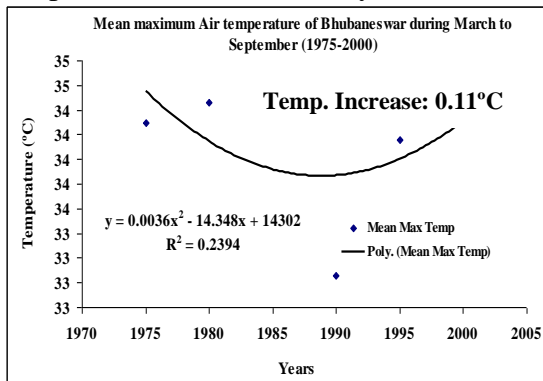
Puri

The mean maximum and minimum air temperature during March to September during 1975-2000 has increased by 0.75°C and 1.76°C respectively.
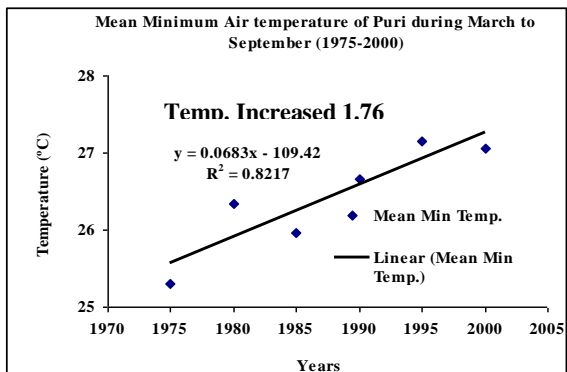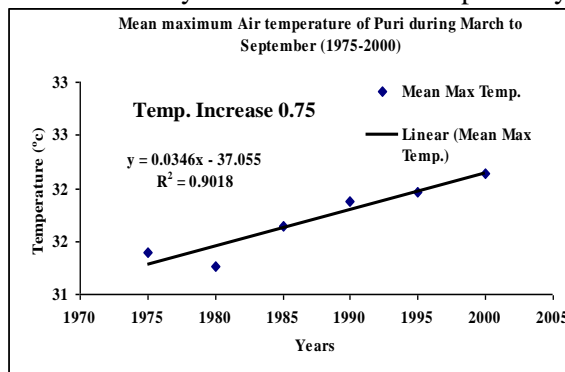
Balasore

The mean minimum air temperature during March to September during 1975-2005 has increased by 0.31°C and mean maximum air temperature has increase by 0.74°C.

135
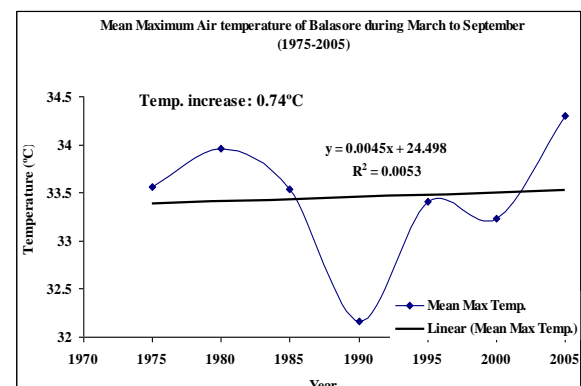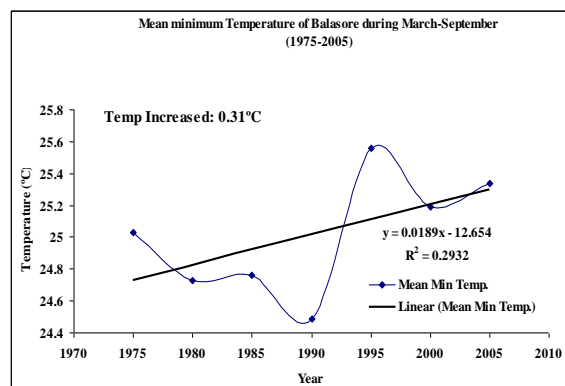
Minimum & maximum water temperature at Balasore

Basing on the worked out relation between air and water temperature, the equation y =0.614x + 11.64, R2 = 0.89 was put into the recorded air temperature in breeding season months of March-September in the last three decades and the mean minimum water temperature during 1975-2005 has increased by 0.99ºC and mean maximum water temperature has increase by 1.49ºC at Balasore.
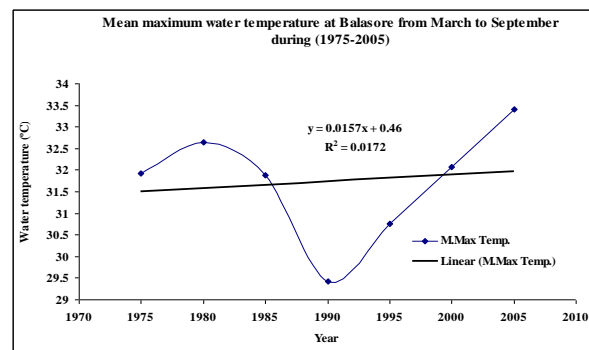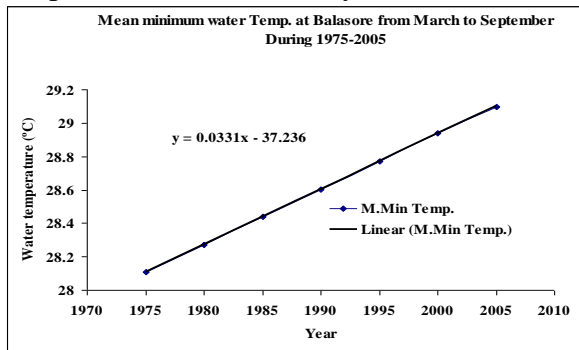
Advancement of breeding period in Mayurbhanj & Balasore districts

Breeding period of hatcheries in Mayurbhanj district is advanced by over 60 days during the last decade. Presently season starts by 15-20th April as against 15th-20th June earlier.
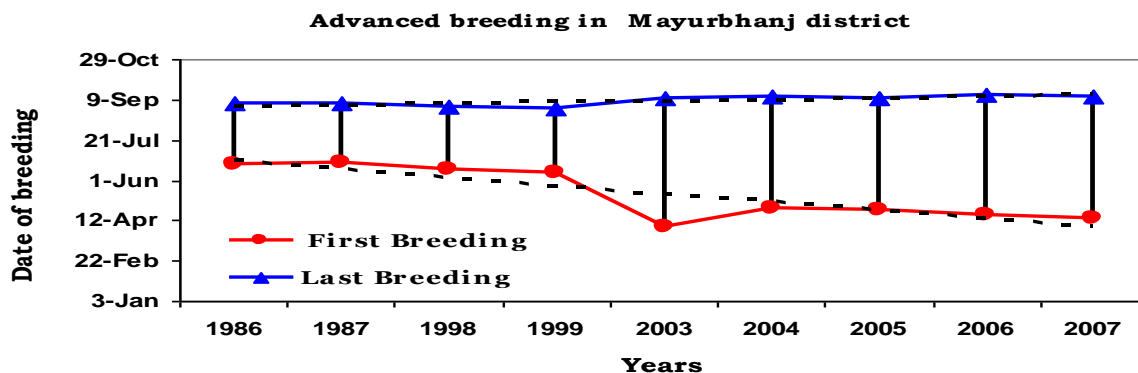
In Balasore district the season starts with first breeding by 15th-20th May while during pre 2000 breeding used to start during 3rd week of June thus showing advancement by over a month.
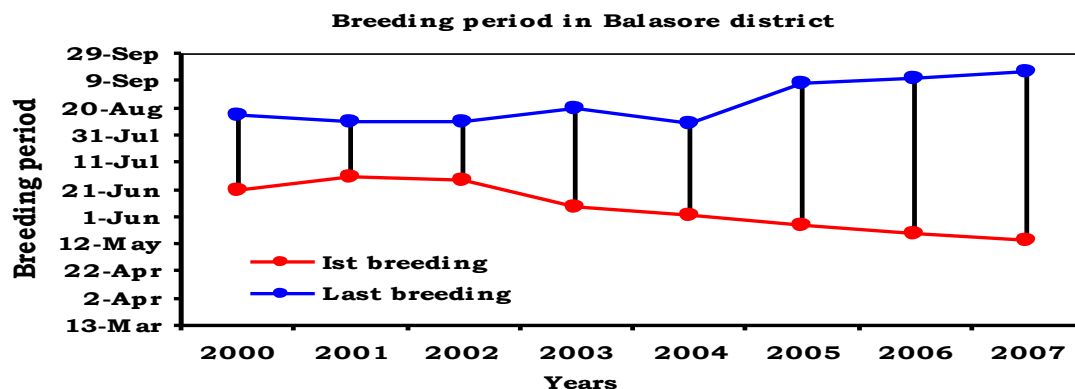
Breeding period in fish seed hatcheries at Puri & Khurda district

In Puri district breeding of IMC showed advancement by a month with breeding starting by 21st June during 2007 as against 2nd week of July during pre 2000.

Advancement of breeding period in hatcheries in Puri district
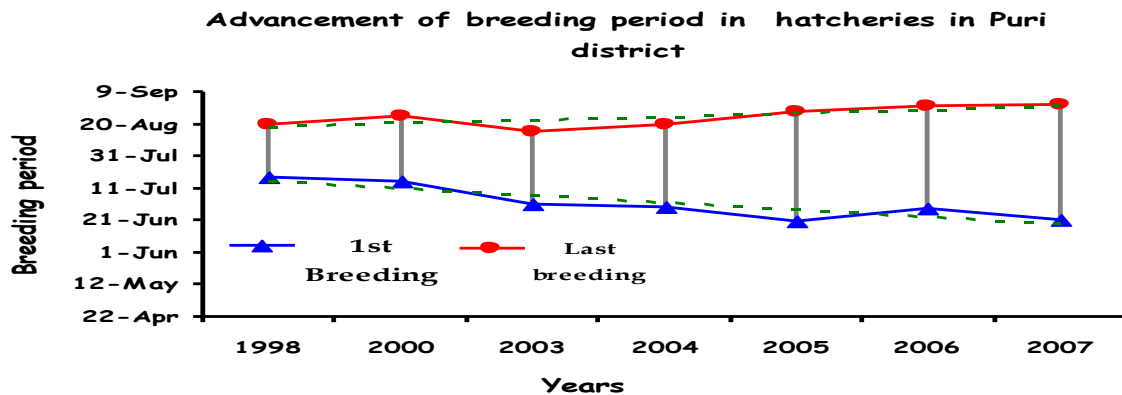
In Khurda district the breeding period in the fish seed hatcheries lasts 75 days while it lasted 30-40 days earlier.

Breeding period in some hatcheries in Khurda district
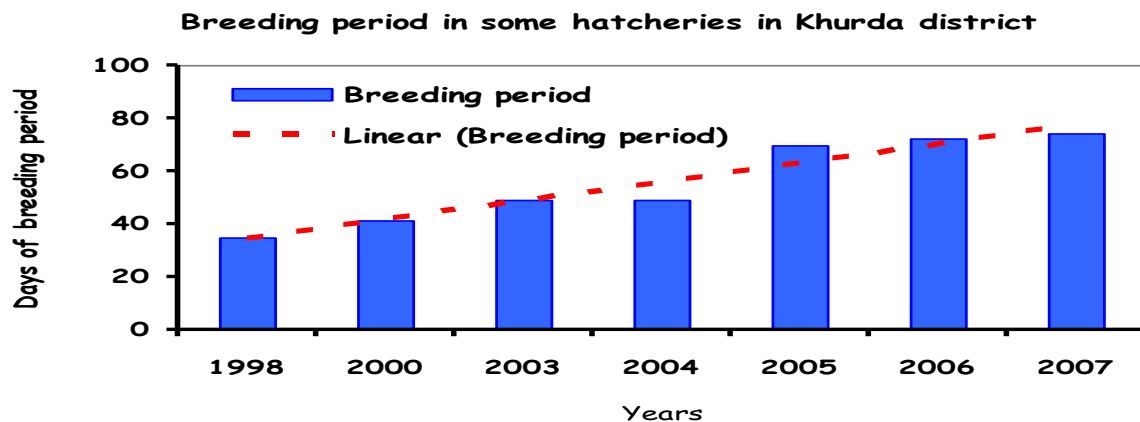
Changes in Rainfall Pattern

Since rainfall is another important criteria that triggers the early maturation of the fish brooders the rainfall pattern of the districts of Orissa where the fish seed hatcheries were suyveyed were analysed from data available from IIMT Pune. The Annual rainfall data were clubbed into two blocks of pre 90's (1980-89) and post 90's (1981-2005) since most of the fish seed hatcheries came up during this period in the state of Orissa. The months were clubbed into January-April,May-August,Sept-Dec blocks and the variation in annual rainfall during the two time periods were analysed.

District- Khordha

In Khorda district there is a distinct shift of rainfall pattern with the rainfall increasing in Sept-Dec months from 26% to 31% where as in Jan-April months the increase ranged

from 6% during 1980-99 to 14% during 1990-2005. Thus the percent increase in rainfall in Jan to April months might have induced early maturation of the fishes resulting in advanced breeding and an extended breeding period nowadays in the fish seed hatcheries.

Rainfall pattern in Khordha district during 1980-2005
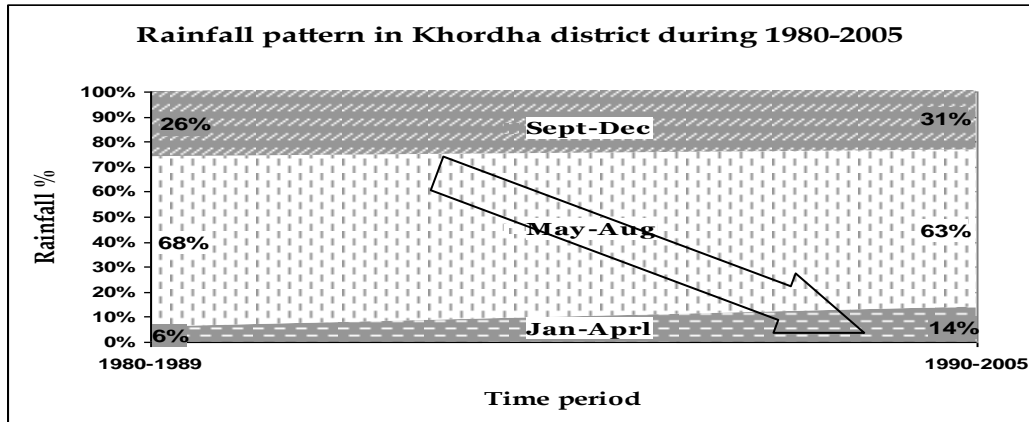
District Balasore

In Balasore district during the time period 1980 to 2005 there is a distinct shift in rainfall towards the March-May months. The rainfall has increased from 14.68% to 18.35% during these months and during Dec-Feb months the increase was from 3.95% to 4.07%. Since rainfall play an important role in triggering fish maturation for breeding the availability of an extended rainfall pattern might induce fish to breed early which might have resulted in the advancement of the breeding period in the fish seed hatcheries in the district

Rainfall distribution pattern at Balasore district 1980-2005
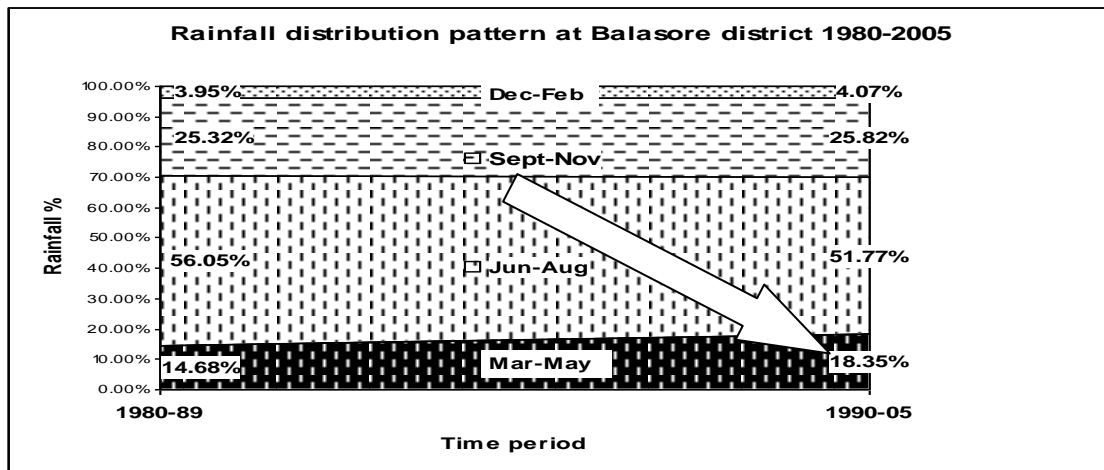
District Puri

In Puri district the rainfall pattern has increased from 4.86% to 6.61% in the January-April during time period of 1980-89 to 1990-2002.

Rainfall pattern in Puri district during 1980-2002
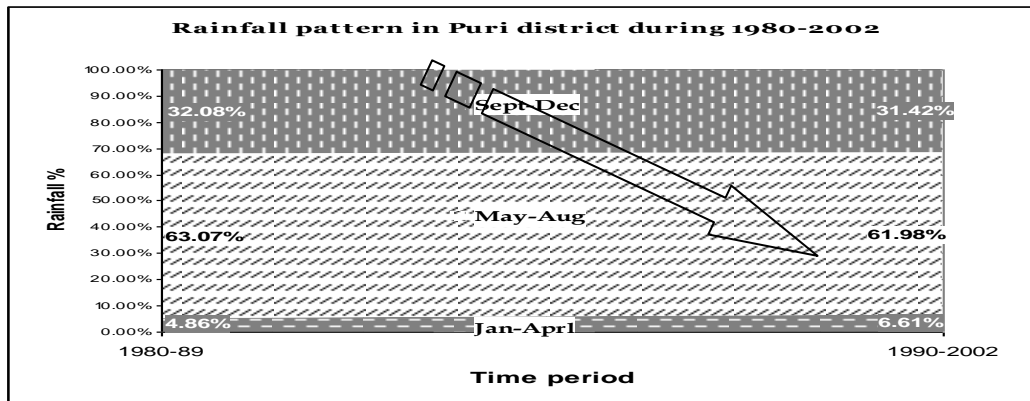
This study indicated an extended fish hatchery activity as compared to a couple of decades ago. This extension has resulted in availability of a longer period of breeding activity of the Indian Major Carps. A couple of decades ago fish spawning season in the fish seed hatcheries used to start with the onset of monsoon in the months of June-July and extended till end September. Chako and Kuriyan 1948, Menon et al.1959 published the same view as well. Under natural conditions, Asiatic major carps breed only once a year In all the fish hatcheries surveyed, fish brooders used to be bred once or twice in a season a couple of decades ago where as nowadays hatcheries follow concept of multiple breeding where brooders are bred more than twice a year inducing by hypophysation.

Temperature has been reported as one of the dominant factors influencing the reproductive cycle in fishes. Maturation process of gonad of carps commence during February-March when temperature gradually increases and completes prior to onset of monsoon (May-June).During these five months (February-June) temperatures in India gradually increase and reach to their maximum. This environmental factor stimulates the endocrine glands which help in the maturation of gonads in carps.

This is assumed to be an effect of sustained rise in temperature. Thus the increased water temperature might have facilitated the advancement in the breeding activity in the fish seed hatcheries. In the fish seed hatcheries surveyed although there is a general belief that temperature might be one such factor, other factors such as early demand with high price might have also induced the fishers to go for an advanced breeding. Going for an advanced breeding requires other activities such as better brooder management with includes better feeding practices, use of vitamins, involving improved manpower, improved healthcare management etc. The present practice of breeding the fish more than two times in a season is attributed to the fact that the favorable temperature for development of gonads is usually found nowadays in the months of January-February, which triggers the gonads to develop and spawn by March-April. According to Bhowmick et al. 1977 spawning by hypophysation can be performed at interval of 36-77 days after first spawning. Previously suitable temperature was used to be available in March-April and fishes used to spawn by May. The present scenario can be attributed to availability of suitable temperature and enhanced advanced rainfall distribution during

march-may months for gonadal development at an earlier time in the breeding season which facilitates earlier spawn availability and more quantity.

The impacts of elevated temperature have resulted in prolonged breeding activity in the fish seed hatcheries resulting in increased total production of spawn thus enhancing seasonal income among the hatchery owners in spite more competition along the years with the coming up of more hatcheries which is a positive impact on socio economic development in the last two decades. Thus shift in breeding period in the fish seed hatcheries in the districts of Balasore, Khordha, Puri and Mayurbhanj can be attributed to the early summer and curtailed winter which may be a result of increase in temperature along with change in rainfall pattern with early rainfall, awareness and improvement in the aspects of brooder management, breeding technique, fish health monitoring andtraining.

Objective 2

Survey of River Mahanadi & Brahmani

Sampling was undertaken along the stretches of River Mahanadi at spots Naraj, Munduli in Cuttack district, Tikarpara in Angul district, Kantilo in Nayagarh district and Jenapur & Sialia inn Jajpur district on River Brahmani. Eighty (80) no. fishermen folk were interviewed regarding spawn availability, fish catch, species availability, fishing techniques, marketing and income in pre & post 90's**.**

Fish diversity in River Mahanadi and Brahmani

<u>**River Mahanadi**</u>

<u>Species</u>:- *Labeo rohita, Labeo calbasu, Labeo bata, Ctenophryangdon idella, Notopterus chitala, Wallagu attu, Vacha, Mystus vittatus , Pangasius sutchi, Mystus aor, Rita chrysea, Puntius ticto Chanda nama, Macro brachium malcomsonii, Macro brachium rosenbergi.*

<u>**River Brahmani**</u>

Species:-*Ompok pabda, Labeo rohita, Labeo calbasu, Wallagu attu , Mystus aor, Cirhannus mrigala, Mystus tengra, Notopterus notopterus, Puntius ticto, Mastacembelus armatus, Xenontodon cancilla Amphipnous cuchia ,Channa punctatus, Pseudoambasis ranga.*

During the study the fishers response towards the changing scenario were recorded. Apart from the decrease in fish catch which has come down from 50-60 kg to 10-15 kg per day during the peak season the percentage of Major carps catch has decreased significantly. Presently only 10% catch constitutes Indian major carps dominated by *Labeo calbasu* while the rest consist of minor carps dominated by *labeo bata,* catfishes and others.

Fish Spawn availability

The fish spawn availability has decreased drastically. Previous records of 1954, 1962, 1963 has stated the availability of average total spawn to be 30-43 ml/net/day where as presently it is 6 ml/net/day.
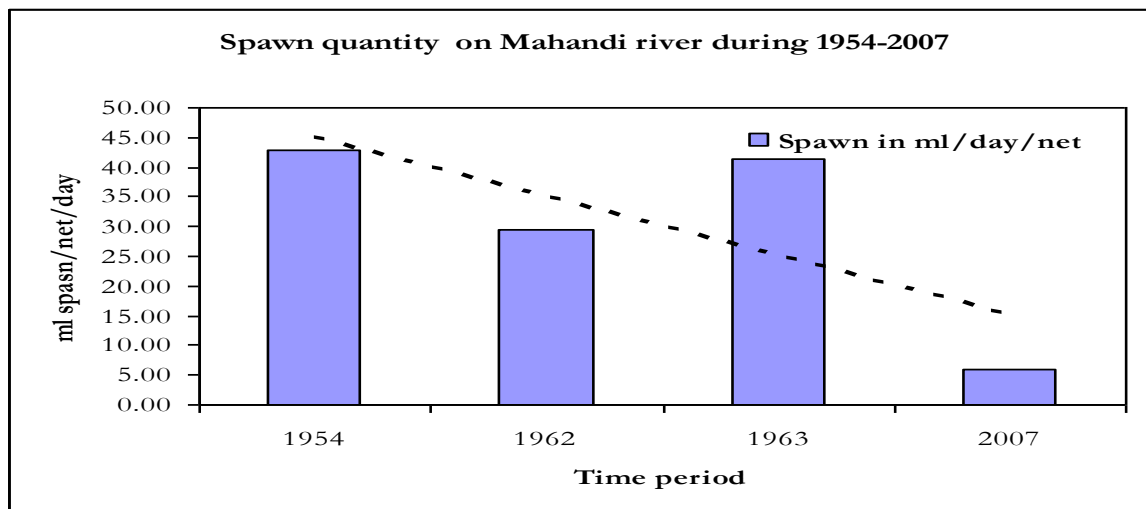
Fishers response towards changing scenario

	Criteria	Response %				
	SCENARIO	**RIVER MAHANADI**			**RIVER BRAHMANI**	
		Naraj	**Mundali**	**Tikarpara**	**Sialia**	**Jenapur**
1.	Decrease in spawn availability.	99	95	95	95	95
2.	Decrease in fish catch.	90	95	90	95	95
3.	High cost & maintenance of crafts & gears.	80	80	75	90	90
4.	Low sell price.	80	80	90	75	75
5.	Inadequate marketing & storage facilities.	95	95	95	95	95
6.	Decrease in man hr/day	60	70	30	80	60
7.	Migration to other profession	20	20	10	40	20
	Reason					
1.	Rise in temperature	75	75	80	90	90
2.	Decrease in rainfall	95	95	90	95	95
3.	Change in rainfall pattern	95	95	95	95	95
4.	Siltation	90	90	70	90	95
5.	Floods	80	75	60	75	75
6.	Decrease in water level	80	80	80	70	70
7.	Poisoning & pollution	50	50	60	75	75

Impact of rainfall and temperature pattern on the fish in the river basin

Rainfall and temperature form two important criteria for fish gonadial maturation and its breeding behaviour and spawning. While comparing the scenario during pre 90's with the post 90's the rain fall pattern and the temperature both maximum and minimum during the two years were analysed to see the changes if any which might have altered the breeding behaviour of the fishes in the river basin.

River Mahanadi.

The sampling centers on river Mahanadi were at Mundali & Naraj in Cuttack district and Tikarpara in Angul district. The sampling centers on river Brahmani were Jenapur and Sialia in Jajpur District. The annual rainfall and its distribution and the mean maximum temperature of the districts Cuttack and Angul were analysed.

Rainfall

The rainfall patterns at Cuttack and Angul district show a decreasing trend in the last decade. The annual rainfall in Cuttack district has decreased by 18.275 mm and in Angul by 7.452 mm during time period 1970-2005.

Rainfall in cuttack district during 1970–2004

Rainfall pattern changes in district Cuttack during 1971-2000
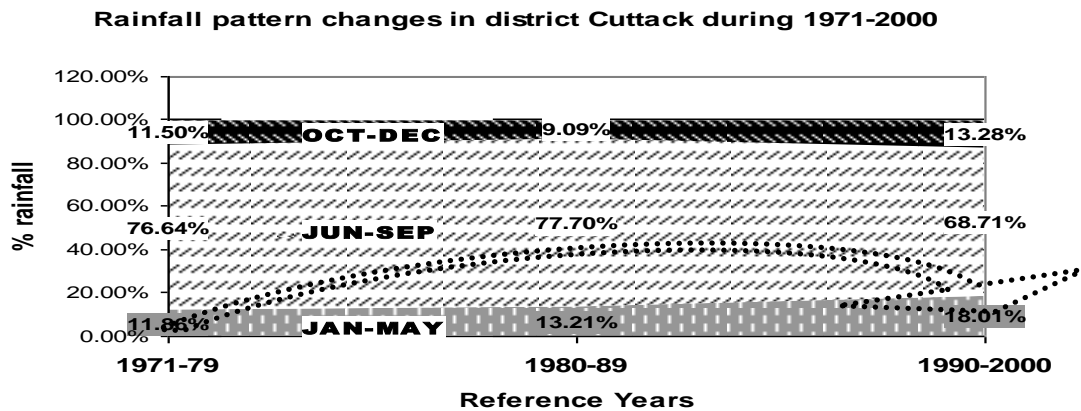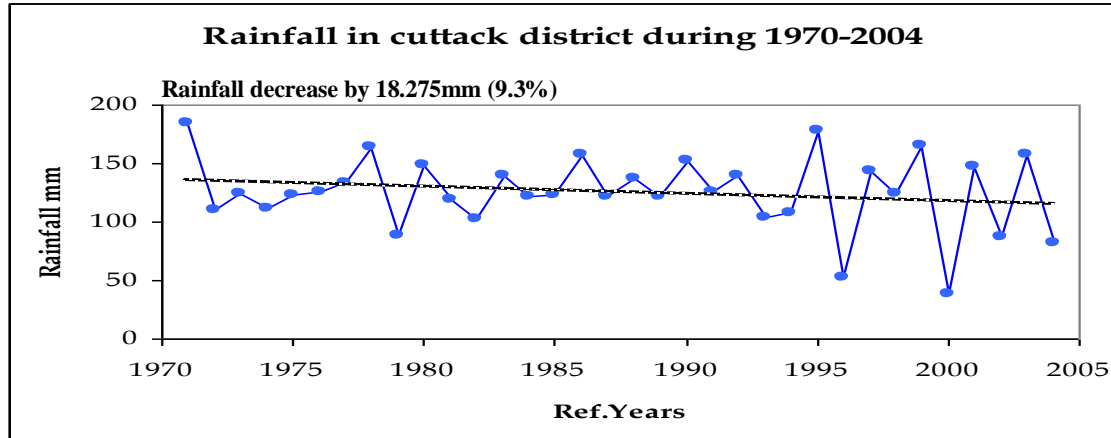
The seasonal pattern at Cuttack also shows changes in rainfall pattern with increase from11.86% to18.01% in the January- May months where as decrease from 76.64% to 68.71% during June-September during the last three decades 1970-2000. In Angul district the percentage of rainfall has decreased from 78.69% to 62.76% during June –September where as it has increased from 13.32% to 17.09% in Jan-May months and from 7.99% to 20.15% during October –December months. Since June-September months are considered as breeding period of fishes, any alteration might disturb the normal breeding of fishes and its spawning.

Rainfall at Angul district during 1970-2004

Rainfall in mm (y-axis): 40.0 to 140.0
Years (x-axis): 1970 to 2005

Rainfall decrease by 7.452 mm

$$y = -0.2192x + 538.23$$
$$R^2 = 0.0159$$

Rainfall distribution at Angul district 1970-2000

Rainfall% (y-axis): 0.00% to 120.00%
Ref. Years (x-axis): 1970-78, 1980-89, 1990-2000

	1970-78	1980-89	1990-2000
OCT-DEC	7.99%	10.42%	20.15%
JUN-SEP	78.69%	74.27%	62.76%
JAN-MAY	13.32%	15.32%	17.09%
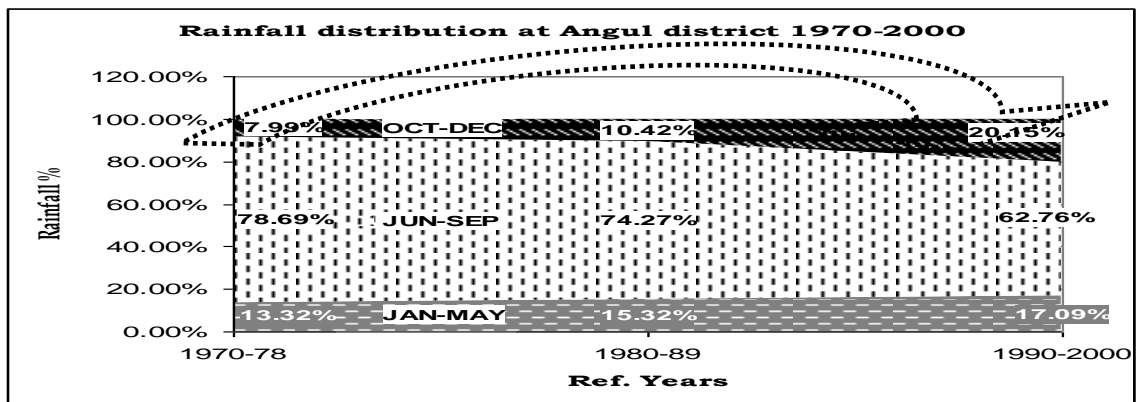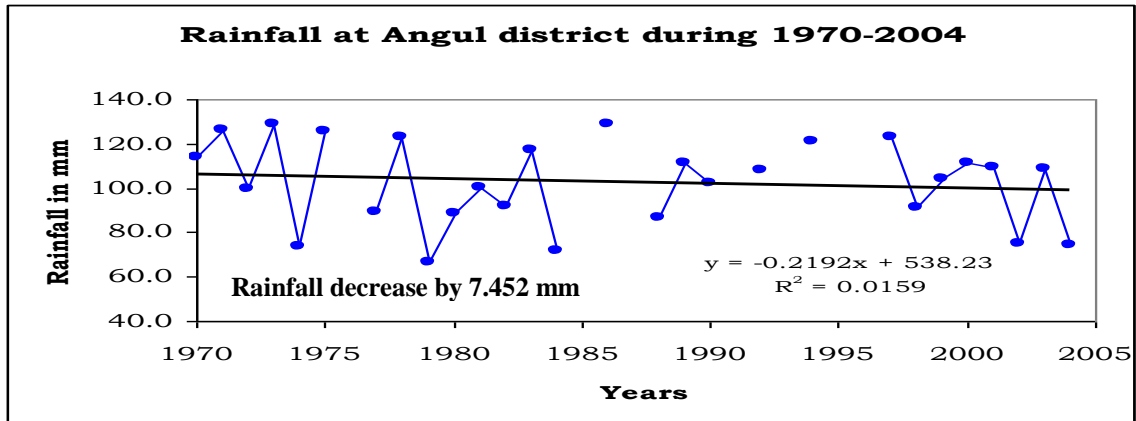
Temperature

The mean maximum temperature at Cuttack district has increased by 1.38ºC and in district Angul by 0.42ºC last three decades

Mean maximum temperature at Cuttack 1972-2004

Temperature ºC (y-axis): 29.0 to 38.0
Reference Years (x-axis): 1 to 33

Temperature increase 1.38ºC

Mean maximum temperature at Angul district during 1970-2004
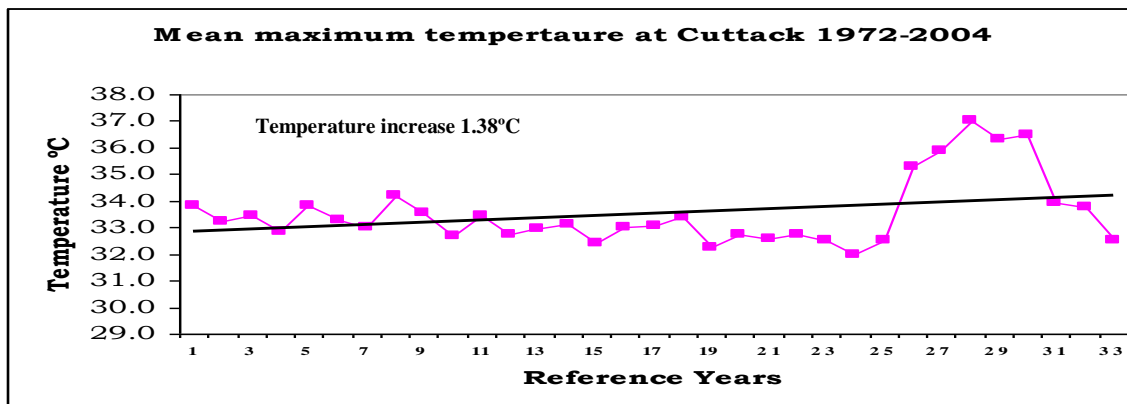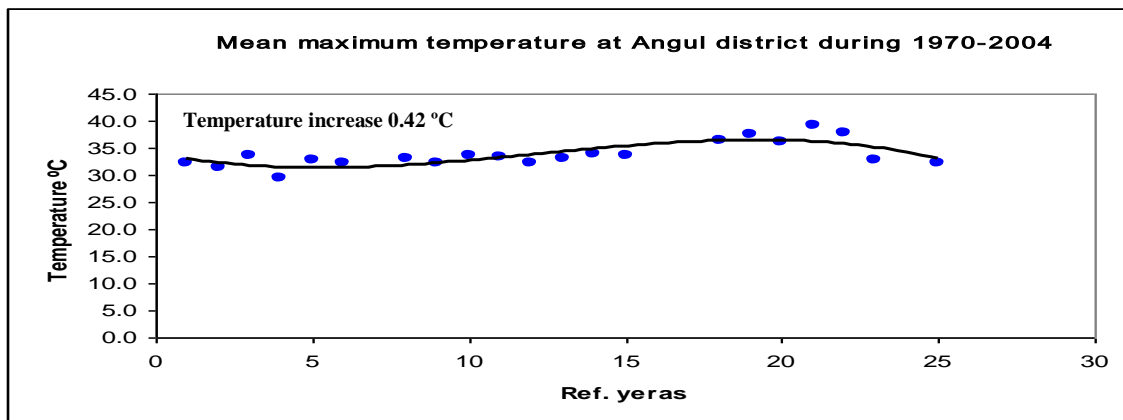
In the case of fish seed hatcheries where the fishes are bred in captivity induced by hypophysation, increase in pre monsoonal rain and increase in temperature might influence the fishes to mature early leading to early spawning which results in an extended breeding period as depicted in the fish seed hatcheries in districts Khorda, Puri, Balasore and Mayurbhanj previously. In case of riverine fishes which breed naturally in rivers, any increase or decrease in temperature or erratic rainfall during the breeding season months (which in case of carps is usually during June to September) may alter the breeding behaviour. Changes in climatic factors viz. rainfall and temperature might disturb the normal natural spawning of the fishes in the rivers. In study spots on river Mahanadi, there has been changes in the rainfall pattern and increase in mean maximum temperature in the both the districts in the last three decades which might be a factor in drastic decrease in spawn availability and decrease in fish catch. Some fishes easily adapt to the changing environment while some are very sensitive to climatic factors, this might have been the reason for the percentage drop of Indian major carps catch in comparison to hardy catfishes.

River Brahmani

Sampling were also undertaken at two spots at Jenapur & Sialia in district Jajpur on river Brahmani and the study is in progress**.**

Objective: 3
Impact of Climate Change on Riverine Fisheries in India
River studied:

Study of the following 15 major rivers throughout India

i.	Brahmaputra	ix.	Periyar
ii.	Cauvery	x.	Savarmati
iii.	Ganga	xi.	Subarnarekha
iv.	Godavari	xii.	Tapi
v.	Krishna	xiii.	Beas
vi.	Mahanadi	ivx.	Sutlej
vii.	Mahi	vx.	Damodar
viii.	Narmada		

Data:

The data were collected for each river from different published sources. Since the data on the parameters for different rivers were not available for each year, we considered the data for the year from1994 to2007, almost all the parameters for each river were available within this period. i.e. Our study period was 1994-2007, about one and half decade.

Along with fish species richness, we determined the following parameters as variables obtained from different websites and published literature within the study period for middle stretch of each river.

i. The mean annual water temperature (in °C)
ii. Mean annual water temperature range (in °C)
iii. Annual total rainfall (in mm)
iv. Mean annual discharge (m^3/s)
v. Mean annual sediment load (000 MT/Km^2/Yr)
vi. Mean annual runoff (B.C.M):
vii. Climatic zones: The climate of India was classified into four major zones based on amount of rainfall and its pattern. The zones were ranked using Likert`z scaling procedure by considering various characteristics, which are suitable for fish population in the zones. The climatic zone assigned to each river corresponds to the largest climatic area drained by the middle part of the river.
viii. Mean latitude (Degree and second) of river basin was taken as average of latitude and was weighted by its length. The values for mean latitude are for the center of each river basin.

and

ix. Total area of drainage basin (Km^2).

The main objective was to find out a best possible combination or subset of independent variables expressing the dependent variable among fish species richness of river with relatively greater multiple R^2-value. Relations between the variables were tested by standard regression, using a set of linear contrasts for each variable. In "statistical methods" the order in which the predictor variables are entered into (or taken out of) the model is determined according to the strength of their correlation with the criterion variable. Several versions of such method include forward selection, backward elimination and stepwise selection regression techniques to derive the optimum subset of the independent variables with maximum contribution to the among-river variation in fish species richness. The R^2 - statistic provides the proportion of variance in the criterion variable, which is accounted for by the regression model. Using SPSS package performed all these statistical analyses were performed.

Results

Table: 1.1: Relation in terms of Regression Co-efficient (r^2) between fish species richness (log scale) and other environmental variables with observed P-value i.e. Probability associated with F- test and n number of plots (n=15).

Variables	r^2	P
Total surface area of drainage basin*	0.566	0.004
Mean annual discharge*	0.684	0.001
Mean annual water temperature	0.101	0.361
Annual temperature range*	0.250	0.185
Annual total rainfall*	0.476	0.006
Mean annual sediment load*	0.481	0.031
Mean latitude*	0.474	0.042
Mean annual runoff*	0.470	0.051
Climatic zone-1	0.378	0.082
Climatic zone-2	0.251	0.196
Climatic zone-3	-0.044	0.438
Climatic zone-4	-0.457	0.043

*Variables expressed in logarithmic values

The stepwise selection regression procedure showed that the criterion variable fish species richness was closely related to factors associated to river discharge, rainfall and area of the river basin (Table: 1.2). Analysis of the results from obtained model (Table: 1.2) showed that fish species richness was significantly correlated with three independent variables that together explained 72.7% of total variability; the rainfall explained more of the variations in the species richness (e.g. the rainfall with standard coefficient or beta value 0.49,n=15,p<0. 05) than did river discharge and total area of drainage basin with standard coefficient 0.392 and 0.366 respectively.

Table 1.2: The regression model explaining proportion of variation in among-river species richness (criterion variable) by three significant (at 5% level) explanatory variables as under:

Variables	Slope Co-efficient	Beta	P-value
Intercept	-1.059		0.000
Log (mean annual discharge)	0.118	0.392	0.001
Log (annual total rainfall)	0.597	0.487	0.004
Log (total area of drainage basin)	0.183	0.366	0.003

The slopes and standardized coefficients of predictable variables against log (species richness), after controlling for the effect of other variables analysis used stepwise procedure in multiple regression analysis to retain only variables with significant partial correlations (p<0.05). Examinations of residual values were performed at each step of the procedure. Final multiple regressions emerged a highly significant model (F = 9.767. n =

15. $R^2=0.72.7$, $P=0\ 002$). Forward and backward multiple regressions yielded similar results.

Fig 1.1: (A) Relationships between the number of freshwater fish species observed and the number predicted by multiple regression Straight lines represent points at which the predicted value equals the observed value.
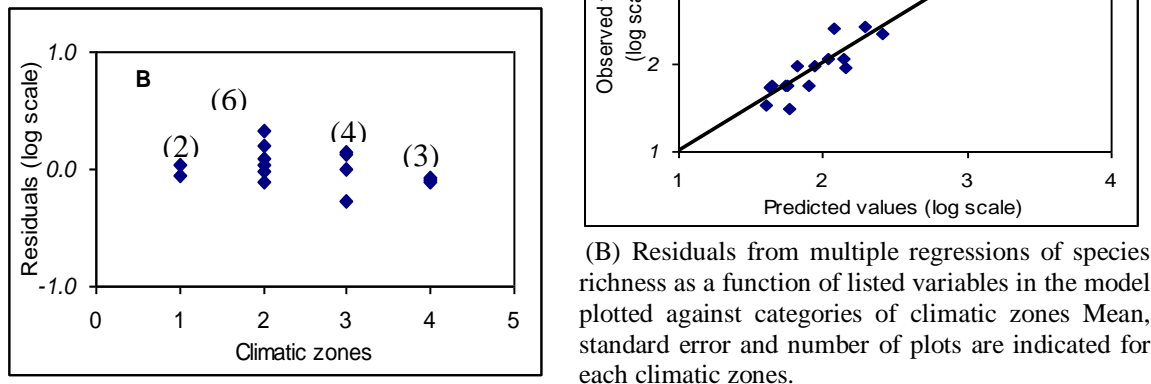
(B) Residuals from multiple regressions of species richness as a function of listed variables in the model plotted against categories of climatic zones Mean, standard error and number of plots are indicated for each climatic zones.

As can be seen by examining the relationship between observed values and those expected (Fig 1.1A) based on the multiple regressions, the combination of variables used in the model achieved a good fit (by Chi-square test, 1.68, df=15) of the data with no obvious signs of nonlinearities.

To test the influence of climate on fish species richness, we proceeded by analyzing residual variation in the model versus the 4 climatic zones (Fig. 5B) Student's t-tests showed that variation of average species richness residuals for zones 2 (t=3.01, p<0.005), zone 3(t=2.26, p<0.05), zone 4 (t= -1.84, p<0.05) differed significantly from a null value. Adding climatic zones as dummy variables (Draper and Smith 1981) in the model confirmed this result ($R^2=0.798$, n=15, p<0.005). Thus, the model overestimates species richness in rivers for climatic zones 2 and underestimates for zone 4 (Fig 1.1B). This suggests that species richness depends upon "something" that co-varies with climatic zones and is not included in the model, thereby giving support, at this step of investigation, to the influence of climatic history and/or contemporary climate on fish species richness. The Study is under progress.

Conclusion:
The main target of this study was to identify predictors of freshwater fish species richness in rivers of India. The data analyses presented here lead to the conclusion that climatic variable rainfall and to a lesser extent, river discharge and surface area of the drainage basin, are the most important factors influencing fish species richness patterns in India. Considering only these three descriptors, without explicit information concerning primary productivity one cannot statistically explain most of the natural variability of freshwater fish species richness in India. So, climate change may be a most responsible factor for

future fish availability in Indian rivers. According to the patterns and explanations presented here, the various effects of human activity in the ecosystems, in particular, apart from pollution, the flow modification of river (mainly due to reservoir construction and use of water for agricultural practices) may have a profound effect on species richness.

N.B: Study on rivers with climatic zone effect separately and future scenarios of species richness patterns in rivers of India is under progress.

Objective: 4

Growth of fish under simulated temperature regime

In continuation to earlier experiments on growth normal of 29ºC and six levels of temperature (1ºC (30ºC), 2ºC (31ºC), 3ºC (32ºC) 4ºC (33ºC), 5ºC (34ºC) and 6ºC (35ºC) above normal, were selected for feeding efficiency and growth performance study in fish in relation to increase in ambient temperature. Study was conducted to estimate the effect of temperature on feeding cycling on specific growth of *L. rohita* fingerlings. Thermostatic and mechanically aerated wet chambers of 90 × 35 × 30cm size were utilized as test containers. Advance fry of *Labeo rohita* (1.39 ± 0.01291 g.) acclimated in laboratory conditions and adapted to formulated palletised artificial feed (Ingredients wheat flour & whole egg. Dry matter: 92.28%, Crude protein: 33.13%, Crude lipid: 11.53%, Ash: 12.67%) were used as test specimens. Besides maintaining water temperature, aeration at regular intervals was continued for the experimental duration. Acclimatised fishes were introduced in each experimental container and fed *ad libitum* with formulated feed every morning. Survivality and growth in fish were recorded for analysis.

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.

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 34% over that of 29ºC. But at 35ºC the rate of growth was arrested to almost that of the fishes exposed to 29ºC temperature.

The specific growth 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 29ºC and further by 17.18% at 34ºC.At 35ºC the SGR of the fishes decreased by 16.23% of that of 34ºC.

Growth of *Labeo rohita* fingerlings under different temperture range
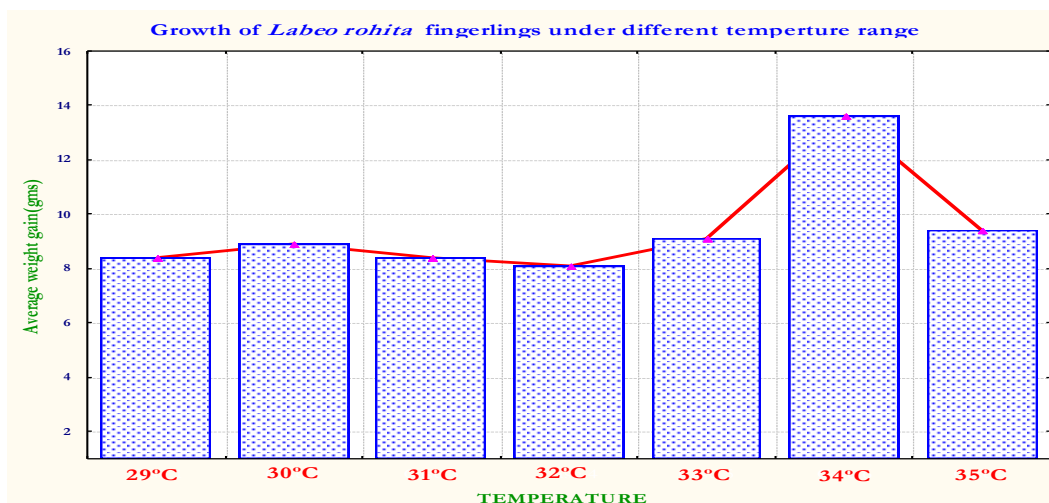
Under controlled laboratory conditions, the fingerlings of *L. rohita* (1.39 ± 0.01291 g.) kept in different temperatures and *ad libitum* feeding showed conspicuous responses for their food conversation, food consumption, specific growth and weight gain with thermal variations in ambient waters. The 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. With 4ºC increase in temperature from 29ºC to 33ºC the value raised up by 12.29 % and the increase was up to 38.69% 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% compared to of 34ºC. Within this temperature range, the maximum weight gain at 34ºC after compilation of experiment. Finding of the present investigation will help towards effective aquaculture management strategies of changing temperature for major carp.

TAMILNADU AGRICULTURAL RESEARCH INSTITUTE, COIMBATORE

Objective 1

1. Construction of Composite Vulnerability Index

Vulnerability to Climatic Change (CC) a comprehensive multidimensional process affected by large number of related indicators and hence it is necessary to measure the quantum of vulnerability by constructing a vulnerability index for each district. Hence, it can be well represented by composite indices. Composite indices are used as yardsticks to gauge the vulnerability of each region to CC.

Methodology for construction of vulnerability index

Methodology developed by Iyengar and Sudharshan (1982) to workout a composite index from multivariate data was used to rank the districts in terms of their economic performance. The methodology is well suited for the development of composite index of vulnerability to CC also.

It is assumed that there are M regions/districts, K components for vulnerability and C_k is the number of variables in component k so that X_{ic_k} is the value of the variable c_k of the kth component for the ith region $(i = 1, 2, 3...m; k = 1, 2, 3...K)$. First, these values of vulnerability indicators which may be in different units of measurement are standardized. When the observed values are related positively to the vulnerability, the standardization is achieved by employing the formula

$$y_{id} = (X_{id} - Min\, X_{id})/(Max\, X_{id} - Min\, X_{id})$$

where $Min\, X_{id}$ and $Max\, X_{id}$ are the minimum and maximum of $(X_{i1}, X_{i2},....X_{in})$ respectively. When the values of X_{id} are negatively related to the vulnerability, the standardized values will be computed by the formula

$$y_{id} = (Max\, X_{id} - X_{id})/(Max\, X_{id} - Min\, X_{id})$$

Obviously these standardized indices lie between 0 and 1. The level or stage of development of dth zone is assumed to be a linear sum of y_{id} as

$$\overline{y_d} = \sum_{i=1}^{m} w_i\, y_{id}$$

Where w's $(0 < w < 1\; and \sum_{i=1}^{n} w_i = 1)$ are the weights determined by

$$w_i = \frac{k}{\sqrt{var\,(y_i)}}$$

$$k = \left[\sum_{i=1}^{n} \frac{1}{\sqrt{Var(y_i)}} \right]^{-1}$$

The choice of the weights in this manner would ensure that large variation in any one of the indicators would not unduly dominate the contribution of the rest of the indicators and distort inter zone comparisons.

For classificatory purposes, a simple ranking of the zone indices viz., y_d would be enough. However for a meaningful characterization of the different stages of vulnerability, suitable fractile classification from an assumed distribution is needed. One probability distribution, which is widely used in this context, is the Beta distribution. This distribution is defined by

$$f(z) = x^{a-1}(1-x)^{b-1} / b(a,b), \quad 0 \pounds x \pounds 1 \; and \; a,b > 0.$$

This distribution has two parameters a and b. They can be estimated either by using the method described in Iyengar and Sudharshan (1982) or by using software packages. The Beta distribution is skewed. Let $(0, z_1), (z_1, z_2), (z_2, z_2), (z_3, z_4)$ and $(z_4, 1)$ be the linear intervals such that each interval has the same probability weight of 20 per cent. These fractile intervals can be used to characterize the various stages of vulnerability.

1.	Less vulnerable	If	$0 < y_d < z_1$
2.	Moderately Vulnerable	If	$z_1 < y_d < z_2$
3.	Vulnerable	If	$z_2 < y_d < z_3$
4.	Highly vulnerable	If	$z_3 < y_d < z_4$
5.	Very highly vulnerable	If	$z_4 < y_d < 1$

This index is a composite one constructed on the basis of several factors, which are prone to be affected by climatic change. Following Patnaik and Narayanan (2005), these factors can be grouped into five components namely, 1.Demographic 2. Climatic 3. Agriculture 4. Occupational and 5. Geographic. Each one of these components can have several sub-indicators. The vulnerability indices derived by applying statistical techniques can be used to classify the coastal districts into five different categories namely, less vulnerable, moderately vulnerable, vulnerable, highly vulnerable and very highly vulnerable.

Fig. Districts/Agro-Climatic Zones of Tamil Nadu State, India

a) Demographic vulnerability

There are three components involved in this index to explain the demographic patterns of the people living in the respective district.

i.   Density of population (persons per square kilometer)
ii. Literacy rate (percentage)
iii. Infant mortality rate (deaths per '000 infants)

b) Climatic vulnerability

This index tries to take into account basic climatic variability. It combines six separate indices which are the variances of

i.   Annual rainfall (mm^2)
ii. South west monsoon (mm^2)

iii. North east monsoon (mm^2)
iv. Maximum temperature ($^{\circ}$C^2)
v. Minimum temperature ($^{\circ}$C^2)
vi. Diurnal temperature variation ($^{\circ}$C^2)

c) Agricultural vulnerability

This includes the following variables to predict the vulnerability related to agricultural activities.

i. Production of food grains (tonnes / hectare)
ii. Productivity of major crops (tonnes/ hectare)
iii. Cropping intensity (percentage)
iv. Irrigation intensity (percentage)
v. Livestock population (Number per hectare of net sown area)
vi. Forest area(percentage geographic area)

d) Occupational vulnerability

Six indicators were taken to calculate the vulnerability related to occupational characteristics of people and all these variables are converted into per hectare of net sown area.

i. Number of cultivators
ii. Total main workers
iii. Agricultural labourers
iv. Marginal workers
v. Industrial workers
vi. Non workers

e) Geographic vulnerability

i. Coastal length (kilometer)
ii. Geographical area (hectare)

Measuring vulnerability for different agro climatic zones of Tamil Nadu

The values of the vulnerability index and the corresponding ranks of the different agro climatic regions of Tamil Nadu are shown in Table1. It can be observed that the vulnerability of the people to climate change is very high in the hilly zone followed by southern zone as compared to the other agro climatic zones. Table 2 and 3 gives the ranks of the agro climatic zones for different components of vulnerability and their classification in terms of vulnerability.

Table 1. Vulnerability Index and ranks for different agro climatic zones of Tamil Nadu

S. No	Region/District	Index	Rank
1.	North Eastern Zone	0.5322	4
2.	North Western Zone	0.4172	6
3.	Western Zone	0.5336	3
4.	Cauvery Delta Zone	0.5291	5
5.	Southern Zone	0.5532	2
6.	High Rainfall Zone	0.2709	7
7.	Hilly Zone	0.5873	1

Table 2. Ranks of the agro climatic zones for different components of VI

Agro climatic zones	Demographic	Climatic	Agriculture	Occupational	Geographical	Overall
North Eastern Zone	1	1	4	7	2	4
North Western Zone	4	5	7	3	5	6
Western Zone	2	2	3	4	4	3
Cauvery Delta Zone	3	3	6	2	3	5
Southern Zone	5	4	2	5	1	2
High Rainfall Zone	7	7	5	6	6	7
Hilly Zone	6	6	1	1	7	1

Table 3. Classification of Agro climatic zones in terms of vulnerability

S. No	Classification	Agro climatic zones
1.	Less vulnerable	High Rainfall Zone
2.	Moderately Vulnerable	North Western Zone
3.	Highly vulnerable	Southern Zone Western Zone North Eastern Zone Cauvery Delta Zone
4.	Very high vulnerable	Hilly Zone

Measuring vulnerability of coastal districts

The vulnerability indices for all the 11coastal districts were constructed as per the methodology described earlier. Based on the indices, the coastal districts were ranked and the rankings are given in Table 4. The vulnerability indices were subjected to further statistical analysis for classifying them into different categories. For this Beta probability distribution was fitted to the observed indices and the percentile values at 20, 40, 60, and 80 were taken as cut-off points for the five groups. This resulted in the classification as given in Table 5.

Table 4. Vulnerability Index and ranks for the coastal districts

S. No	Districts	Vulnerability Index	Rank
1	Thiruvallur	0.472	7
2	Kancheepuram	0.491	6
3	Cuddalore	0.500	5
4	Nagapattinam	0.545	2
5	Thiruvarur	0.468	8
6	Tanjore	0.429	10
7	Pudukkotai	0.533	3
8	Ramnad	0.607	1
9	Thoothukudi	0.515	4
10	Tirunelveli	0.342	11
11	Kanyakumari	0.442	9

The Table 5 shows that among the 11 coastal districts Ramnad and Nagapattinam are most vulnerable to climatic change.

Table 5. Classification of coastal districts in terms of vulnerability

S. No	Classification	Districts
1	Less vulnerable	Tanjore Tirunelveli
2	Moderately Vulnerable	Thiruvarur Kanyakumari
3	Vulnerable	Thiruvallur Kancheepuram Cuddalore
4	Highly vulnerable	Pudukkotai Thoothukudi
5	Very high vulnerable	Ramnad Nagapattinam

Measuring vulnerability of all districts in Tamil Nadu

The values of the vulnerability index and the corresponding ranks of all the districts located in Tamil Nadu are shown in Table 6. It can be observed that the vulnerability of the people to climate change is very high in the Perambalur district followed by The Nilgiris and Ramnad as compared to the other districts. The ranks of the districts for different components of vulnerability are given in Table 7. The resulted classification in terms their vulnerability is given in Table 8.

Table 6. Vulnerability Index and ranks for all districts Tamil Nadu

S. No	Region/District	Index	Rank
1.	Thiruvallur	0.4234	22
2.	Kanchipuram	0.4434	19
3.	Vellore	0.5138	6
4.	Dharmapuri	0.4870	11
5.	Thiruvanamalai	0.5048	9
6.	Villupuram	0.5077	8
7.	Salem	0.3760	27
8.	Namakkal	0.4076	26
9.	Erode	0.4859	12
10.	The Nilgris	0.5828	2
11.	Coimbatore	0.5199	5

12.	Dindugal	0.4687	17
13.	Karur	0.4841	13
14.	Trichy	0.4172	24
15.	Perambalur	0.5856	1
16.	Cuddalore	0.4623	18
17.	Nagapatinum	0.5018	10
18.	Thiruvarur	0.4244	21
19.	Tanjore	0.4089	25
20.	Pudukkotai	0.4714	15
21.	Sivaganga	0.5443	4
22.	Madurai	0.4269	20
23.	Theni	0.4711	16
24.	Viruthunagar	0.5080	7
25.	Ramnad	0.5493	3
26.	Thoothukudi	0.4760	14
27.	Thirunelvalli	0.3363	28
28.	Kanyakumari	0.4232	23

Table 7. Ranks of the districts for different components of VI

District	Demographic	Climatic	Agriculture	Occupational	Geographical	Overall
Thiruvallur	19	7	17	27	15	22
Kanchipuram	21	6	15	26	8	19
Vellore	4	1	18	25	11	6
Dharmapuri	27	9	11	6	17	11
Thiruvanamalai	13	2	16	23	9	9
Villupuram	8	4	20	18	7	8
Salem	12	24	26	20	13	27
Namakkal	1	18	28	7	24	26
Erode	11	10	21	11	3	12
The Nilgris	16	23	1	3	28	2
Coimbatore	15	15	5	15	6	5
Dindugal	7	14	24	9	10	17
Karur	2	17	9	13	27	13

Trichy	25	20	12	22	18	24
Perambalur	10	8	7	1	22	1
Cuddalore	3	21	19	14	14	18
Nagapatinum	9	3	25	8	5	10
Thiruvarur	14	12	27	4	25	21
Tanjore	18	25	22	12	16	25
Pudukkotai	20	13	10	17	12	15
Sivaganga	23	5	3	16	20	4
Madurai	17	11	13	24	21	20
Theni	6	16	14	10	26	16
Viruthunagar	5	22	4	19	19	7
Ramnad	28	26	2	2	1	3
Thoothukudi	26	27	8	5	2	14
Thirunelvalli	22	19	23	28	4	28
Kanyakumari	24	28	6	21	23	23

Table 8. Classification of all the districts in Tamil Nadu in terms of vulnerability

S. No	Classification	Districts
1.	Less vulnerable	Trichy,Tanjore, Namakkal Salem,Tirunelveli
2.	Moderately Vulnerable	Kanchipuram,Madurai,Thiruvarur Thiruvallur,Kanyakumari
3.	Vulnerable	Erode,Karur,Thoothukudi Pudukkotai,Theni,Dindugal Cuddalore
4.	Highly vulnerable	Coimbatore,Vellore,Viruthunagar Villupuram,Thiruvanamalai Nagapatinum,Dharmapuri
5.	Very high vulnerable	Perambalur,The Nilgris,Ramnad Sivaganga

Objective 2

Multi Goal Linear Programming (MGLP) for sustainable food security

Multi Goal Linear Programming (MGLP) model

The Ricardian model is used to project the area, production and productivity of major crops under existing and different climate change scenarios. These projected values can be used to estimate maximum possible production in different climate change scenarios by fitting the suitable optimization model. Hence, the multi goal linear programming is a suitable tool to predict the possible changes in the food grain production and utilization of resources under different climate change scenarios.

For planning the sustainable food security and their resource requirements in the different agro climatic zones of Tamil Nadu, the MGLP model can be used. The MGLP model for Tamil Nadu covers all the 30 districts, which can be viewed as a combination of the different agro climatic regions. This model has been used in several studies for land use planning at the state level (Aggarwal *et al.,* 2001), sub-regional and regional level (Schipper *et al.,* 1995; Veeneklaas *et al.,* 1991), village level (Huizing and Bronsveld, 1994) and farm level (Schans, 1991). The model is developed using MATLAB a mathematical modeling and optimization software. The model used for the present study is as follows.

General symbols used in the model

Land Units: $l= 1, 2,... L$
Seasons: $s=1, 2,,…S$
Crops: $c =1, 2,...C$
Technologies: $t=1, 2,…T$
SC = Set of selected crops for maximum production.
$P_c =$ Current production of crop c in Tamil Nadu.

Available resources

$A_{ls} =$ Available land area (ha) in land unit l in season s.

$W_{ls} =$ Available water (m^3) in land unit l in season s.

$L_{ls} =$ Total labour (in man days) available at the land unit l in season s.

$C_{ls} =$ Capital availability (Rs) in land unit l in season s.

Technological coefficients

$x_{lsct} =$ Land area used in land unit l, in season s, for crop c under technology t.

$y_{lsct} =$ Productivity of crop c, in season s in land unit l under technology t.

$w_{lsct} =$ Water requirement per unit area for crop c in season s in land unit l under technology t.

$l_{lsct} =$ Labour requirement per unit area for crop c in season s in land unit l under technology t.

$c_{lsct} =$ Capital requirement per unit area for crop c in season s in land unit l under technology t.

$r_{lsct} =$ Net return from crop c, in season s in land unit l under technology t.

Objective functions

The proposed multi goal linear programming model has the five social, economic and environmental objectives. They are a) Maximizing food grain production, b) Maximizing net income, c)Maximizing employment d) Minimizing agricultural area and e) Minimizing water use

For each of the above objective we included the following constraints one by one:

Land is the only constraint,

Land and Water are the constraints

Land and Technology are the constraints

Land, Water and Technology are the constraints

Land, Water, Technology and Labour are the constraints

Land, Water, Technology and Capital are the constraints

Land, Water, Technology , Labour and Capital are the constraints

Area under each annual crop is same in all the seasons in each land unit

Estimation of resources availability include

Estimation of land resources

Estimation of water resources availability

Estimation of labour availability

Yield estimation at different technology levels

Yield estimation at technology level 1

This methodology was same as followed by Aggarwal *et al.,* (2001). They estimated potential yield at technology level 5 using the various crop growth simulation models and current yield level for technology 1. The required data were collected from them through ICAR Climate Change Network Project and used for the present analysis.

Yields estimation at technology level 2, 3 and 4

The difference between the adjusted potential yield and the calculated current yield in each agro climatic zone was considered as the attainable yield gap for that respective crop. Target yields were set at bridging 25, 50 and 75 per cent of the yield gap for these technology levels of 2, 3 and 4 respectively.

Yield estimation at technology level 5

The measured yields at this level of technology in different agro climatic zones are not available. However, the yield at technology level 5 estimated and simulated by the Aggarwal *et al.,* and the same was collected and used in the present study. Aggarwal *et al.,* (2001) used a variety of crop growth simulation models for the different crops to estimate the potential yields that can be attained in the different agro climatic zones. A complete standard calibration and validation was impossible for the other crops such as

cotton, groundnut and sugarcane. The potential yields were simulated for these crops and further judged on the basis of expert knowledge.

Sowing dates for the different crops were selected depending on the prevailing cropping pattern in the respective agro climatic zones. In general, even under the best management, marketable yield is lower than potential yield because of unavoidable losses through pests and diseases, during harvesting, transportation and processing. These losses were assumed to result in a 10 per cent reduction in potential yield. Therefore, realizable potential yield of an area has been set at 90 per cent of potential yield and these yields were allotted to different agro climatic zones.

Estimation of input requirements for the yields at different technology levels

Calculation of costs of inputs like seed, irrigation, fertilizer and labour were done for different technology levels.

Calculation of byproduct value

The total amount of byproducts produced from the various crop activities were estimated from the target yield and crop specific harvest indices. It can be assumed that 20 per cent of the total byproducts were lost during harvesting and transportation and this will not be available for use. Use the following formula to calculate the total byproduct produced by the different crops.

$$Byproduct = Target\ yield \times 0.8 / Harvest\ Index$$

Crop suitability

Crop suitability is based on their cultivated area for past more than five years in particular season in their respective agro climatic zone. If the particular crop is suitable give 1, otherwise 0.

Description of resources

The natural and socio economic resources available in Tamil Nadu, different technological adaptation followed by various categories of farmers and estimation of potential yield of major crops at different technology levels were elaborately discussed.

Availability of land resources, water resources, capital availability and labour availability were worked out.

Technology description to attain target yields

Technology level in this study is defined as the complete description of the production activity, which includes the target yield level plus all inputs required to realize this target output and all additional outputs such as byproducts of the crops. A major aim is to planning for sustainable food security that combined with the various goals of maximizing food grain production, maximizing farm income from agriculture, maximizing the employment opportunities and others. Thus, the selected different technology levels in the future may exhibit higher yields than the current systems. The various technologies are described in brief as follows.

Technology level 5

This is the maximum potential attainable yield level that could be achieved by the large farmers only. This technology is currently not practiced in Tamil Nadu. It represents knowledge based and intensive mechanized crop production. Target yield are set equal to potential yields. It can be assumed that some well endowed resource rich farmers of Tamil Nadu might adopt this technology in the future. Concepts of precision farming may be used to maximize input use efficiency through high-tech agriculture including site specific and integrated nutrient, water and pest management. It can be made use of special equipment such as tractor-mounted implements and micro and high volume chemical applicators in combination with liquid fertilizers. It has been assumed that the full cost of all implements will not be borne by the farmers directly. This heavy and costly equipment will be made available to them from the government organizations and farmer's cooperative societies. The cost of hiring this equipment has been included at a rate of rupees 4,000 per hectare per crop. In view of high mechanization activities, human labour use is assumed to decrease up to 40 per cent. Overall, this technology is expected to result in a considerable increase in food production and net income of the farmers although the capital requirement is also much higher.

Technology level 4

Target yield for this technology in the various zones for different crops was set to current yield plus bridging the 75 per cent of the yield gap. This is also similar to technology 5 with more input use efficiency and knowledge intensive technology but this is followed with partially mechanized crop production has been assumed for technology 4. Input use efficiencies are higher than in technologies 1, 2 and 3, but slightly lower than the technology 5 and also it requires relatively lower capital.

Technology level 3

This technology can be achieved by target yields are set to current yield plus 50 per cent of the yield gap for the particular crops in each zone. Again, these higher yields are supported by input intensification, in proportion to the increase in yield.

Technology level 2

Target yields were achieved in this technology were set to the current yield plus bridging the 25 per cent of the yield gap. Agricultural practices similar to these in technology 1 were assumed. The higher yields were obtained by assuming the intensification of input use in proportion to the increase in yield.

Technology level 1

This technology is current practice followed by the farmers in different agro climatic zones of Tamil Nadu and this is considered as the baseline level. The average yield rate of major crops in Tamil Nadu is higher than the national average. The farmers depending on their land resources and capital availability they will select the different production techniques. In this study, however, we have used the average conditions of the farming activities in the state to define this technology. In general, the mechanization level is medium, ploughing is usually done with a tractor and tillage implements and levelling of fields is done at a very rough scale. Sowing and application of fertilizers are mostly done with manually. The use of

organic manure is low on an average, farmer use less than one tonne of farmyard manure per hectare.

Maximizing food grain production

Land is the only constraint

Rice is the major food grain in Tamil Nadu with the total production of about 5 million tonnes per year in a total area of 18.73 lakh hectares. The maximum attainable rice production in Tamil Nadu is 16.19 million tonnes from the current level of production of five million tonnes with production of other crops maintained at their current level. To produce this level of output, Tamil Nadu has to use 100 per cent of cultivable land, needs 50.43 billion m^3 of water, 52.61 billion rupees of capital, 272 million labour days of employment, 0.49, 0.19 and 0.11 million tonnes of nitrogen, phosphorus and potash respectively. If these resources are made available, farmers could generate an income of 116.91 billion rupees from the current level of 47.09 billion rupees per annum and this is higher by about 70 billion rupees from the current income of our farmers. These resource requirements are several times higher than the current availability of resources and hence this level cannot be achieved in practice.

Land and water are the constraints

In addition to land, the available water is added as an additional constraint to determine the maximum possible rice production in all the agro climatic regions of Tamil Nadu. Under this constraint, rice being the largest consumer of water in the state, rice production dropped to 7.06 million tonnes – a reduction of 9.13 million tonnes from maximum production under when land alone is the constraint, keeping production of other crops at their current level. As shown in Table 28, to realize this level of rice production Tamil Nadu needs 23.96 billion m^3 of water, 73.91 percentage of land area, 33.69 billion rupees of capital, 245.38 million labour days. It will generate a net income of 66.49 billion rupees against 116.91 billion rupees when land alone is the constraint. Further fertilizer requirements drastically dropped to 0.39 million tonnes from 0.79 million tonnes. The above results show that water is the major limiting factor for agriculture in Tamil Nadu. The above level of rice production is possible only when 44 per cent of the land area is allotted to technology level 5.

Land and technology are the constraints

In the third stage, technology adoption by various categories of farmers is introduced as another constraint in addition to the land resources. In this case, maximum attainable rice production will be 14.51 million tonnes. Water requirement is nearly doubled which is 45.64 billion m^3 compared to current availability because water is not added as the constraint in the model. Capital and net income of the farmers decreased about 10 and 7 per cent respectively. However, employment opportunities increased to 10 per cent compared to the first case. Fertilizer requirement also decreased compared to first case (a). This level is also not possible because water is the major limiting factor.

Land, water, technology and labour are the constraints

When land, water and technology adoption were simultaneously introduced as constraints, the rice production decreased to 7.06 million tonnes. About 77 per cent of available cultivated land, 34 billion rupees of capital, 24 billion m^3 of water and

264 million labour days of employment are needed to produce this level of output. This will give 66 billion rupees of net income annually to our farmers in the different agro climatic zones of Tamil Nadu. When labour also included, there is no change in the level of rice production which shows that labour is not a limiting factor.

Land, water, technology, labour and capital are the constraints

Capital is a major socio economic resource for the marginal and small farmers. When this is also included as a constraint, the rice production is further decreased to 6.64 million tonnes compared to all other cases. Here the land utilization is only 70 per cent of the available land. The utilization of all other resources considerably reduced. Figure 2 shows the land use pattern when all the constraints were taken into account.

Finally to summarize the above results indicate that it is possible to increase the total rice production by 1.58 million tonnes, which accounts for 31.23 per cent more than the existing current level from the different agro climatic regions of Tamil Nadu even by imposing all the constraints. Net income of the farmers will also increase from 47.09 to 65.20 billion rupees. This is higher by 18.11 billion rupees and shares 38.45 per cent more income to our farmers in Tamil Nadu compared to what they are earning at present.

It can be observed that when land is the only constraint, all land area is utilized under the highest technology level (Tech 5), which gives maximum productivity. When water is included as a constraint, technology 5 gets only 44 per cent of the land area while other technologies get around 13 per cent of the land each and about 26 per cent of the land area is left unutilized. But when all the constraints are included technology 5 gets only 36 per cent and about 30 per cent of land area becomes unutilized, technology 4 gets 27 per cent of the land and about 12 per cent of the land is obtained by each one of the other three technologies. When water is not included as a constraint the MGLP model utilizes the 100 per cent of the land area. This again emphasizes the conclusion that water is the major constraint for agricultural production in Tamil Nadu.

Maximizing farm net income

Land is the only constraint

Farm net income of the farmers from major crops in Tamil Nadu would reach a maximum of 198.90 billion rupees from the current level of earning of 47.09 billion rupees, which is about 152 billion rupees higher, and this is 322 per cent higher than the existing level of income. Also in this scenario, the production of all crops will be greater than or equal to their current level. To generate this level of net income, Tamil Nadu needs 100 per cent of available land, 51.96 billion rupees of capital, 48.58 billion m^3 of water and 280.56 million labour days. Cotton production will reach 18.99 million bales compared to current level of 0.19 million bales and sugarcane production will also increase from 24.46 to 29.56 million tonnes and other crops will maintain their current level of production.

To achieve this level of net income, the capital level has to increase from 36 billion rupees to 52 billion rupees. Similarly, water available should be increase from 24 billion m^3 to 48.58 billion $m^{3.}$ These resources are neither currently available nor they do become available (especially water) in the next two or three decades and hence this level of maximum net income is not possible.

Land and water are the constraints

When availability of irrigation water is include as a constraint, the net income drops to 124 billion rupees, which accounts for a decrease of 37.71 per cent of the net income when land is the only constraint. In this scenario, only 85 per cent of land will be utilized and requirements of capital, water and labour are below the levels needed when land is the constraint. To generate 123.89 billion rupees of net income, the resource requirements are 23.71 billion m^3 of water, 41.89 billion rupees of capital and 210.07 million labour days of employment. The production of groundnut will be five times more than the current level and sugarcane production will also from 24.46 to 33.72 million tonnes.

Except capital all other resources are within the available limits and 5 billion rupees of extra capital are needed and farmers should go to technology level 5 which will give maximum productivity. Thus, this is achievable only the farmers to adopt the largest technology (Tech 5) with additional capital.

Land and technology are the constraints

With technology adoption constraint in addition to constraint on land, the net income of the farmers can be maximized to 174.77 billion rupees by cultivating all the land area. This scenario will produce maximum cotton and sugarcane and the production of other crops will be maintained at current level. One important feature of this scenario is the increase in the employment opportunities (312.37 million labour days), this is higher than the corresponding values for other scenarios. The capital and water requirements are respectively 48.34 billion rupees and 42.28 billion m^3, fertilizer consumption will be more than the current level of consumption. But this solution seems to be infeasible because of extremely high amount of resources needed which are not currently available especially water.

Land, water, technology, labour and capital are the constraints

The addition of labour and capital as constraints reduce the farm income. The net income of the farm decreases to 121.19 billion rupees when labour is also a constraint, whereas the farm income will come down to 98.29 billion rupees when capital is also added. Employment generation will decrease to 246.82 and 205.87 million labour days due to the addition of respective constraints.

When these two resources (labour and capital) are together included as a constraints, the farm income drops to 98.29 billion rupees. The resource requirements of 22.05 billion m^3 of water, 34.16 billion rupees of capital and 205.87 million labour days are needed to achieve this level of farm income. When all the constraints are introduced, the percentage contribution by different crops to net income and area under different crops when farm income is maximized indicate that, at the aggregate State level, even with all constraints are included, the farm income is higher by about 51 billion rupees which constitutes 108 per cent higher than the existing level of income.

Percentage land area under different technology levels, when farm income maximized indicated that almost all the land area is used by highest technology level 5, when land is the only constraint. Irrigation water requirement has introduced an additional constraint, the land utilization is distributed about 82, 15 and 3 per cent to technology level 5, 4 and 2 respectively and remaining 15 per cent of the land is left unutilized.

When all the constraints are included, technology 5 gets only 32 per cent and technology 4 gets 54 per cent of the land and about 9 and 5 per cent of the land is utilized by technology 3 and 4 respectively. About 20 per cent of land area becomes unutilized and this also clearly indicates that water is the major limiting factor for crop production in Tamil Nadu. This solution seems to be feasible as the requirement of all the resources are within the available limits and farmers have to practice the modern technologies (Tech 4 and 5).

Maximizing employment

Land is the only constraint

Maximization of employment opportunities in agricultural sector is another social objective of the present study. Production of major crops and their resource requirements for Tamil Nadu at an aggregated level is presented in Table 32, when employment is maximized. The maximum employment potential in different agro climatic regions of Tamil Nadu is about 527.92 million labour days, when land is the only constraint. This is associated with 5.73 million tonnes of rice production compared to the current level of 5.06 million tonnes. The production of cotton will increase from 0.19 million bales to 5.74 million bales and groundnut production will also increase to 1.78 million tonnes from the current level of 1.01 million tonnes and production of other crops is maintained at their current level. To generate this level of employment, 100 per cent of the agricultural land, 29.98 billion meter^3 of water and 52.22 billion rupees of capital will be needed. In addition to increased employment, this will generate an annual income of 98.48 billion rupees. Fertilizer consumption will be more than the current level of consumption. This is not feasible because addition of 5 billion meter^3 of water and addition of capital is required.

Land and water are the constraints

In addition to land resource, water availability is included as a constraint, the employment opportunities will reduce to 472 million labour days. Rice production will be maintained at current level along with other crops except cotton and groundnut which will increase relative to the current level of production. This is due to an increased area under labour intensive and water use efficient cotton and groundnut crops. Annual farm income also decreased to 69.74 billion rupees, utilizing the resource requirements of 46.55 billion rupees of capital and 22.67 billion meter^3 of water. Fertilizer consumption will increase to 0.19, 0.08 and 0.05 million tonnes of nitrogen, phosphorus and potash respectively when compared to current consumption. Area under technology 1, 2 and 3 is predominantly utilized when land and water are the constraints. This solution is feasible only when capital is increased to another 10 billion rupees and farmer shift from current technology to technologies 2 and 3.

Land and technology are the constraints

When technology adoption and land are the only constraints, the employment opportunities will be generated at the same level when land alone was the constraint. Rice production will not undergo any change and it will be the same level of 5.73 million tonnes when land alone was the constraint. Cotton production will reach up to 5.74 million bales compared to current level of 0.19 million bales and groundnut production will also increase from 1.01 to 1.78 million tonnes and other crops will maintain their current level of production. Fertilizer consumption will increase to 0.40 million tonnes from the current consumption level of 0.10

million tonnes. In this scenario the resource requirements of water, capital and fertilizer consumption is high when compared to current level, so this is not feasible solution.

Land, water and technology are the constraints

When technology adoption is included along with land and water constraints, employment generation will drop to 472 million labour days from 528 million labour days when land alone is the constraint. Rice production will decline to their current level along with other crops except for cotton and groundnut, which will increase relative to the current level. To generate this level of employment, the resource requirements are 22.67 billion m^3 of water and 46.55 billion rupees of capital. This will give 69.74 billion rupees of net income annually to our farmers in Tamil Nadu compared to current level of 47.09 billion rupees. This solution is feasible only if there is an increase of 30 per cent of capital.

Land, water, technology, labour and capital are the constraints

When labour is added as a constraint, employment generation is dropped to 350 million labour days by utilizing the 94 per cent of the land. It will generate a net income of 73 billion rupees against the current income of 47 billion rupees but it requires 41 billion rupees of capital and 0.42 million tonnes of fertilizer which is higher than the current level. Whereas capital is added as a constraint, the employment opportunities will be marginally increased to 365 million labour days compared to current level of employment. This requires 18.79 billion m3 of water and 35.81 billion rupees of capital which is lower than the current level.

When labour and capital are together added as constraints, the employment opportunities were drastically reduced to 350 million labour days from the maximum level of about 528 million labour days when land alone is the constraint. For this, it needs 19.81 billion m^3 of water, 87.95 per cent of land resources and 35.73 billion rupees of capital, which generates a net income of 57.44 billion rupees of agricultural per year. Fertilizer consumption will increase to 0.13, 0.04 and 0.05 million tonnes of nitrogen, phosphorus and potash respectively when compared to current level. By introduction of all the constraints the per cent contribution by different crops to the total employment are given .

Percentage area of agricultural land under different technology levels are presented in Table 33 and Figure 7, when employment is maximized. It can be observed that when land is the only constraint, all land area is utilized under the technology level 3 which requires maximum labour. This is due to technology 3 requires maximum number of labour days compared to first two levels of technologies and last two technologies (Tech 4 and 5) will comes under mechanization. When water is included as a constraint, technology 3 gets only 78 per cent of the land area while technology level 1 and 2 gets 20 and 2 per cent of land area respectively. But when all the constraints are included technology 3 gets only 34 per cent, technology 1 gets 37 per cent of the land and about 27 per cent of the land is obtained by technology level 2. When water is not included as a constraint, the model utilizes the 100 per cent of the land area under the technology level 3. This again emphasizes water is the major constraint for agricultural production in Tamil Nadu.

Minimizing agricultural area

Land is the only constraint

Agricultural area was minimized while targets of production of all crops were kept at their current levels. This objective gains importance in view of the need for additional land requirement for housing, industry and infrastructural facilities due to increase in population. Table 34 provides production and area of the six crops and utilization of all resources when agricultural area is minimized. When land is the only constraint, the current output of the major crops can be obtained only by utilizing only 44.45 per cent of the agricultural land. It is also interesting to note that in this scenario, farm income in different agro climatic zones of Tamil Nadu will be 32.81 per cent higher than the current net income earned by our farmers.

To achieve this Tamil Nadu requires 24.17 billion rupees of capital, 18.49 billion m^3 of water and 120 million labour days. Interestingly, this resource requirement is lower than the current availability. But there is a considerable loss of employment opportunities from agriculture due to reduction in agricultural area. As expected, 100 per cent of the land area is cultivated under highest level of technology (Tech 5), which consumes less labour and gives more productivity to give the maximum production from the minimum area. This solution is feasible only when the farmers adopt the highest technology level 5 to maintain current production of crops by utilizing only 45 per cent of its currently cultivated area.

Land and water are the constraints

When irrigation water is included as a constraint, the land area is marginally increased to 45.16 from 44.45 per cent when land alone is the constraint. In this scenario, the employment opportunities will decline by 8 million labour days and this will generate a net income 62.48 billion rupees. Fertilizer consumption will increase to 0.23, 0.09 and 0.08 million tonnes of nitrogen, phosphorus and potash respectively when compared to current consumption.

Land, water and technology are the constraints

In addition to land, when constraint of technology adoption is included, the required minimum agriculture area to maintain the current level production will increase from 1672 to 1735 thousand hectares. One important feature of this scenario is the increase in the employment opportunities to 130.33 million labour days, which is higher than the corresponding values for other scenarios. This target can be achieved from 24 billion rupees of capital and 18.54 billion m^3 of water and it will generate a net income of 63 billion rupees.

Land, water, technology, labour and capital are the constraints

When labour and capital are introduced as constraints separately to the previous case (c), the minimum agricultural area increases to 1767 and 1769 thousand hectares respectively when compared to land is the only constraint (1672 thousand hectares). In both the scenarios, it utilizes 18 billion m^3 of water, 23 billion rupees of capital and 122 million labour days of capital to generate a net income of 65 billion rupees.

When these two resources of labour and capital are together added as constraints, the minimum agricultural area will increase to 47.03 per cent from the 44.45 per cent when land alone is the constraint. This will generate the maximum farm income of 65 billion rupees to the farmers from the agricultural activities when compared to all other cases. This is 38 per

cent higher than the current income generated by our farmers by utilizing only 47 per cent of the currently cultivated area. To generate this level of net income, the resource requirements are 18.27 billion m^3 of water, 22.98 billion rupees of capital and 122.91 million labour days of employment. All these resource requirements are less than the current consumption levels.

To summarize the above results, in all the scenarios of area minimization, the resource requirements will be less (land area, capital, water and labour days) when compared to current level of utilization. Also, the net income will increase by about 15 billion rupees in all the cases which is higher than the existing level of income generated by our farmers. However, the employment potential will reduce drastically when compared to current level of employment opportunities. Thus, this solution is feasible only when the farmers to adopt the modern technology levels of 4 and 5.

Percentage area of agricultural land under different technology levels are presented in Table 35, when agricultural area is minimized. As expected, all the 100 per cent of cultivated land area will distribute to the modern technologies (Technology 4 and 5) in all the scenarios. This is due to the reason that technologies 4 and 5 will give the maximum level of productivity.

Minimizing water use

Land is the only constraint

The earlier scenario analyses revealed that water availability was the major constraint to increase food grain production in the State of Tamil Nadu. Therefore, in this scenario a minimum water requirement was determined to produce current levels of crop production. In this situation, the model generates higher net income by utilizing lesser amount of capital and land area when compared to current level. At the same time, resource requirements are 18.24 billion m^3 of water, 234.61 million labour days and 0.30 million tonnes of fertilizer consumption.

Land and water are the constraints

In addition to land, the available water is added as an additional constraint to determine the minimum possible water requirement for agriculture in all the agro climatic regions of Tamil Nadu. Under this constraint, rice consumes about 51 per cent of the total water requirement to maintain current level of its production. Other crops will utilize the remaining amount of water and the production will be at their current level.

Land and technology are the constraints

Technology adoption by various categories of farmers is included as a constraint in addition to the land resources. In this case, to realize this current level of crop production Tamil Nadu needs 18.24 billion m^3 of water, 65.72 per cent of land area, 28.91 billion rupees of capital and 237.97 million labour days. Fertilizer consumption will also increase from 0.1 million tones to 0.29 million tonnes when compared to current level. It will generate a net income of 57.13 billion rupees against 47.09 billion rupees of current level

Land, water, technology, labour and capital are the constraints

When all constraints are gradually added to land resource constraint, there was no change in water use to maintain the current level of production of all crops. Water consumption will still remain as 18.24 billion m^3 in the entire scenario which shows that this will be the minimum water requirement for agricultural activities in Tamil Nadu. However, this is 26.27 per cent lower than the current water requirement. But the resource requirements of capital, labour, land and fertilizer changed when constraints are added.

When all the constraints are included simultaneously, the resource requirements are 18.24 billion m^3 of water, 27.92 billion rupees of capital and 63.39 per cent of the land area. All these resource requirements are lesser than the current consumption level. However the employment potential will drop to 217.64 million labour days from the 360.66 million labour days of employment when compared to current level. This will generate a net income of 58.29 billion rupees against the current level income of 47.09 billion rupees per annum to the farmers in Tamil Nadu. This needs 0.18, 0.07 and 0.06 million tonnes of nitrogen, hosphorus and potash fertilizers respectively which is higher than the current level of consumption.

To summarize all the above results discussed here, in all the scenarios, water minimization will require less amount of resources such as land area, capital, water and labour days when compared to current level of utilization. Also, the net income will increase by around 10 billion rupees in all the cases which is higher than the existing level of income generated by our farmers in Tamil Nadu. However, the employment potential will reduce marginally when compared to current level of employment opportunities. Thus, this solution is feasible only when the farmers adopt all the technologies equally, less water consuming crops and should follow the water saving technologies to minimize the wastage of water.

Percentage area of agricultural land under different technology levels are presented in Table 37, when minimizing the irrigation water. While minimizing the water use, maximum area under cultivation will go to technology 1, because it consumes lesser amount of water compared to other technologies. In this scenario of water minimization, by adding the constraints one by one, percentage of cultivated area has distributed more or less equal to all the technologies except technology level 1 has marginally more area compared to other technologies.

Out of the five objectives discussed, the point of view of food security, the first objective namely, maximizing food grain production should given top most priority and this objective should considered when constraints on all resources are imposed. In this situation, the food grain production were increased from about 5 million tonnes to 6.64 million tonnes for which only the fertilizer consumption will be more and current level of all other resources are sufficient. This seems to be a feasible solution if farmers adopt modern technologies (Technology 4 and 5) for which proper planning has to be made.

Water sharing options
Water is the most precious resource for agriculture in Tamil Nadu. Hence, four different scenarios of water sharing are included in the model:

1. No sharing of water between land units and between seasons
2. Sharing of water allowed between seasons in each land unit.

3. Sharing of water allowed between land units in each season.
4. Sharing of water allowed between land units and between seasons

The results from the study are summarized below.

When food grain production is maximized and water is not shared between land units and seasons the maximum food grain production is 6.64 million tonnes. When it is shared between land units and between seasons it increases to 7.3 million tonnes. Since the current level production is 5.01 million tonnes, there is a possibility to increase the fod production by 50 percent by sharing water between land units in all the seasons.

Similarly, maximum farm net income will range between 98.90 to 121.25 billion rupees against the current level of 47.05 billion rupees. But, there is not much appreciable increase in the employment due to sharing of water. The reason is adoption of technologies which require minimum quantum of labour are selected for adoption (Technologies 1,4 and 5).

When no water is shared the minimum agriculture area required for producing at Least the current level of production of all crops is 1769.09 thousand ha against the current level of 3761.90 th. Ha. There is a marginal decrease in agricultural area when water is shared. A model predicts a minimum water requirement of 18.24 billion m3 (current level 24.73 billion m3) under all scenarios of water sharing to meet at least the current level of production of al the crops considered in the model.

Table 9. Production of major crops, resource requirements and environmental impact at an aggregated level when maximizing food grain production, Tamil Nadu

Particulars	Unit	Constraints							
		LAND	Land+ Water	Land + Tech	Land + Water + Tech	Land + Water + Tech + Labour	Land + Water + Tech + Capital	Land+ Water + Tech+ Labour + Capital	Current level (2004-05)
Rice**	Mtons	16.19	7.06	14.51	7.06	7.06	6.64	6.64	5.06
Maize	Mtons	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Sorghum	Mtons	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Cotton	M bales*	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Groundnut	Mtons	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
Sugarcane	Mtons	24.46	24.46	24.46	24.46	24.46	24.46	24.46	24.46
Land area	1000 ha	3761.90	2780.51	3761.90	2894.10	2834.06	2684.52	2636.92	3761.90
Land used	Per cent	100.00	73.91	100.00	76.93	75.34	71.36	70.10	100.00
Capital	Billion Rs	52.61	33.69	47.94	34.22	33.73	31.79	31.33	36.95
Income	Billion Rs	116.91	66.49	109.03	66.05	66.47	64.77	65.20	47.09
Water	Billion m^3	50.43	23.96	45.64	23.96	23.96	22.76	22.76	24.73
Employment	M.Labour days	271.99	245.38	302.23	263.79	254.15	235.38	226.01	360.66
Nitrogen	Mtons	0.49	0.23	0.42	0.22	0.22	0.22	0.22	0.05
Phosphorus	Mtons	0.19	0.09	0.16	0.09	0.09	0.08	0.08	0.02
Potash	Mtons	0.11	0.07	0.09	0.07	0.07	0.07	0.07	0.03

- Each bale of cotton = 170 kg.
- ** Objective function maximized.

Table 10. Percentage area of agricultural land under different technology levels when food grain production was maximized, Tamil Nadu

Technology level	Constraints						
	LAND	Land+ Water	Land + Tech	Land + Water + Tech	Land + Water + Tech + Labour	Land + Water + Tech + Capital	Land+ Water + Tech+ Labour + Capital
1	0.00	16.88	0.00	18.07	15.87	15.29	13.76
2	0.00	14.22	0.00	15.83	14.40	13.83	12.14
3	0.00	13.01	2.93	14.87	13.73	13.19	11.41
4	0.00	12.43	71.85	19.17	23.64	22.34	26.71
5	100.00	43.46	25.22	32.05	32.37	35.35	35.98
Over all	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 11. Production of major crops, resource requirements and environmental impact at an aggregated level when maximizing farm net income, Tamil Nadu

Particulars	Unit	Constraints							
		LAND	Land+ Water	Land + Tech	Land + Water + Tech	Land + Water + Tech + Labour	Land + Water + Tech + Capital	Land+ Water + Tech+ Labour + Capital	Current level (2004-05)
Rice	M.ton	5.06	5.06	5.06	5.06	5.06	5.06	5.06	5.06
Maize	M.ton	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Sorghum	M.ton	0.25	0.25	0.25	0.25	0.25	1.62	1.62	0.25
Cotton	Million bales*	18.99	0.19	14.95	0.19	0.19	0.19	0.19	0.19
Groundnut	M.ton	1.01	5.02	1.01	4.94	4.91	2.67	2.67	1.01
Sugarcane	M.ton	29.56	33.72	31.45	34.35	34.87	32.16	32.16	24.46
Land area	Thousand ha	3761.90	3177.05	3761.90	3389.99	3412.13	2984.92	2984.92	3761.90
Land used	Per cent	100.00	84.45	100.00	90.11	90.70	79.35	79.35	100.00
Capital	Bilion rupees	51.96	41.89	48.34	42.56	42.84	34.16	34.16	36.95
Income**	Bilion rupees	198.90	123.89	174.77	121.38	121.19	98.29	98.29	47.09
Water	Billion m^3	48.58	23.71	42.28	23.67	23.68	22.05	22.05	24.73
Employment	Million Labour days	280.56	210.07	312.37	243.65	246.82	205.87	205.87	360.66
Nitrogen	M.ton	0.47	0.30	0.43	0.29	0.30	0.28	0.28	0.05
Phosphorus	M.ton	0.16	0.12	0.14	0.12	0.12	0.10	0.10	0.02
Potash	M.ton	0.19	0.12	0.16	0.10	0.11	0.10	0.10	0.03

* Each bale of cotton = 170 kg.
** Objective function maximized.

Table 12. Percentage area of agricultural land under different technology levels when net income was maximized, Tamil Nadu

Technology level	Constraints						
	LAND	Land+ Water	Land + Tech	Land + Water + Tech	Land + Water + Tech + Labour	Land + Water + Tech + Capital	Land+ Water + Tech+ Labour + Capital
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	3.02	0.00	2.83	2.81	5.30	5.30
3	0.00	0.00	2.93	0.00	0.00	9.11	9.11
4	0.64	14.72	71.85	69.18	69.38	53.80	53.80
5	99.36	82.26	25.22	27.99	27.81	31.79	31.79
Over all	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 13. Production of major crops, resource requirements and environmental impact at an aggregated level when maximizing Employment, Tamil Nadu

Particulars	Unit	Constraints							
		LAND	Land+ Water	Land + Tech	Land + Water + Tech	Land + Water + Tech + Labour	Land + Water + Tech + Capital	Land+ Water + Tech+ Labour + Capital	Current level (2004-05)
Rice	M.ton	5.73	5.06	5.73	5.06	5.09	5.06	5.07	5.06
Maize	M.ton	0.29	0.29	0.29	0.29	1.24	0.29	0.31	0.29
Sorghum	M.ton	0.25	0.25	0.25	0.25	0.97	0.25	0.38	0.25
Cotton	Million bales*	5.74	2.41	5.74	2.41	1.36	0.52	1.08	0.19
Groundnut	M.ton	1.78	1.80	1.78	1.80	1.34	1.01	1.01	1.01
Sugarcane	M.ton	24.46	24.46	24.46	24.46	26.75	24.46	24.47	24.46
Land area	1000 ha	3761.9	3667	3761	3667	3522	3341	3308	3761
Land used	Per cent	100.00	97.50	100.0	97.50	93.64	88.84	87.95	100
Capital	Bilion rupees	52.22	46.55	52.22	46.55	41.18	35.81	35.73	36.95
Income	Bilion rupees	98.48	69.74	98.48	69.74	72.98	53.19	57.44	47.09
Water	Billion m³	29.98	22.67	29.98	22.67	22.14	18.79	19.81	24.73
Employment **	Million Labour days	527.92	471.9	527.9	471.9	350.3	364.6	349.9	360.6
Nitrogen	M.ton	0.24	0.19	0.24	0.19	0.24	0.10	0.13	0.05
Phosphorus	M.ton	0.09	0.08	0.09	0.08	0.09	0.03	0.04	0.02
Potash	M.ton	0.07	0.05	0.07	0.05	0.09	0.03	0.05	0.03

* Each bale of cotton = 170 kg.   ** Objective function maximized.

Table 14. Percentage area of agricultural land under different technology levels when employment was maximized, Tamil Nadu

Technology level	Constraints						
	LAND	Land+ Water	Land + Tech	Land + Water + Tech	Land + Water + Tech + Labour	Land + Water + Tech + Capital	Land+ Water + Tech+ Labour + Capital
1	0.00	19.92	0.00	18.96	27.71	40.11	37.09
2	0.00	1.66	0.00	3.59	20.65	31.87	26.79
3	99.39	78.42	99.39	77.46	29.56	28.03	33.57
4	0.00	0.00	0.00	0.00	11.45	0.00	1.58
5	0.61	0.00	0.61	0.00	10.63	0.00	0.97

| Over all | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

Table 15. Production of major crops, resource requirements and environmental impact at an aggregated level when minimizing agricultural area, Tamil Nadu

Particulars	Unit	LAND	Land+ Water	Land + Tech	Land + Water + Tech	Land + Water + Tech + Labour	Land + Water + Tech + Capital	Land+ Water + Tech+ Labour + Capital	Current level (2004-05)
Rice	M.ton	5.06	5.06	5.06	5.06	5.06	5.06	5.06	5.06
Maize	M.ton	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Sorghum	M.ton	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Cotton	Million bales*	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Groundnut	M.ton	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
Sugarcane	M.ton	24.46	24.46	24.46	24.46	24.46	24.46	24.46	24.46
Land area**	1000 ha	1672	1698	1734	1767	1767	1769	1769	3761
Land used	Per cent	44.45	45.16	46.11	46.99	46.99	47.03	47.03	100.00
Capital	Bilion rupees	24.17	23.26	24.00	23.05	23.05	22.98	22.98	36.95
Income	Bilion rupees	62.54	62.48	63.21	64.53	64.53	64.86	64.86	47.09
Water	Billion m³	18.49	18.27	18.54	18.27	18.27	18.27	18.27	24.73
Employment	Million Labour days	119.96	111.92	130.33	122.32	122.32	122.91	122.91	360.66
Nitrogen	M.ton	0.24	0.23	0.23	0.23	0.23	0.22	0.22	0.05
Phosphorus	M.ton	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.02
Potash	M.ton	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.03

* Each bale of cotton = 170 kg.
** Objective function maximized.

Table 16. Percentage area of agricultural land under different technology levels when agricultural area was minimized, Tamil Nadu

Technology level	Constraints						
	LAND	Land+ Water	Land + Tech	Land + Water + Tech	Land + Water + Tech + Labour	Land + Water + Tech + Capital	Land+ Water + Tech+ Labour + Capital
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	45.30	46.32	46.32	46.37	46.37
5	100.00	100.00	54.70	53.68	53.68	53.63	53.63
Over all	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 17. Production of major crops, resource requirements and environmental impact at an aggregated level when minimizing water use, Tamil Nadu

Particulars	Unit	Constraints							Current level (2004-05)
		LAND	Land+ Water	Land + Tech	Land + Water + Tech	Land + Water + Tech + Labour	Land + Water + Tech + Capital	Land+ Water + Tech+ Labour + Capital	
Rice	M.ton	5.06	5.06	5.06	5.06	5.06	5.06	5.06	5.06
Maize	M.ton	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Sorghum	M.ton	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Cotton	Million bales*	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Groundnut	M.ton	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
Sugarcane	M.ton	24.46	24.46	24.46	24.46	24.46	24.46	24.46	24.46
Land area	1000 ha	2470	2545	2472	2542	2430	2440	2384	3761
Land used	Per cent	65.67	67.68	65.72	67.57	64.61	64.87	63.39	100.00
Capital	Bilion rupees	28.79	29.32	28.91	29.28	28.46	28.34	27.92	36.95
Income	Bilion rupees	57.24	56.79	57.13	56.85	57.82	57.79	58.29	47.09
Water**	Billion m^3	18.24	18.24	18.24	18.24	18.24	18.24	18.24	24.73
Employment	Million Labour days	234.61	241.30	237.97	241.98	223.75	226.59	217.64	360.66
Nitrogen	M.ton	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.05
Phosphorus	M.ton	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.02
Potash	M.ton	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.03

* Each bale of cotton = 170 kg.

** Objective function maximized.

Table 18. Percentage area of agricultural land under different technology levels when water was minimized, Tamil Nadu

Technology level	Constraints						
	Land	Land+ Water	Land + Tech	Land + Water + Tech	Land + Water + Tech + Labour	Land + Water + Tech + Capital	Land+ Water + Tech+ Labour + Capital
1	25.94	26.82	25.21	26.82	22.73	23.26	21.12
2	20.91	21.68	22.10	22.18	19.84	19.99	18.78
3	18.58	18.88	19.72	18.67	17.67	17.66	16.83
4	17.35	16.83	17.47	16.71	20.49	20.98	22.93
5	17.23	15.79	15.50	15.61	19.28	18.12	20.35
Over all	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 19. Maximizing Food grain (Rice) Production(in million tonnes)

Particulars	Land	Land + Water	Land + Technology	Land + Water + Technology	Land + Water + Technology + Labour	Land+ Water + Technology + Capital	Land + Water + Technology + Labour + Capital	Current level
WS-NS	16.2	7.06	14.5	7.06	7.06	6.64	6.64	5.01
WS-BSLU	16.2	7.08	14.5	7.08	7.08	6.97	6.97	5.01
WS-BLUS	16.2	7.35	14.5	7.35	7.35	7.34	7.34	5.01
WS-BLUBS	16.2	7.35	14.5	7.35	7.35	7.35	7.35	5.01

WS-NS =No sharing of water; WS-BSLU=Water sharing between season within the land units; WS-BLUS= Water sharing between land
units within the season; WS-BLUBS= Water sharing between land units and between the season.

Table 20. Maximizing Farm Net income(in billion rupees)

Particulars	Land	Land + Water	Land + Technology	Land + Water + Technology	Land + Water + Technology + Labour	Land+ Water + Technology + Capital	Land + Wat... + Technolog... + Labour + Capital
WS-NS	198	1239	174	121	121	98	98
WS-BSLU	198	129	17	127	126	106	106
WS-BLUS	19890	13687	174	133	133	115	115
WS-BLUBS	198	137	174	136	135	121	121

Table 21. Maximizing Employment(in million labour days)

Particulars	Land	Land + Water	Land + Technology	Land + Water + Technology	Land + Water + Technology + Labour	Land+ Water + Technology + Capital	Land + Water + Technology + Labour + Capital	Current level
WS-NS	527	471	527.92	471.97	350.31	364.62	349.97	360.66
WS-BSLU	527	484	527.92	484.01	351.53	366.49	350.62	360.66
WS-BLUS	527	508	527.92	508.53	360.66	380.46	360.63	360.66
WS-BLUBS	527	511	527.92	511.81	360.66	380.46	360.63	360.66

WS-NS =No sharing of water; WS-BSLU=Water sharing between season within the land units; WS-BLUS= Water sharing between land

units within the season; WS-BLUBS= Water sharing between land units and between the season.

Table 22. Minimizing Agricultural Area(in thousand ha)

Particulars	Land	Land + Water	Land + Technology	Land + Water + Technology	Land + Water + Technology + Labour	Land+ Water + Technology + Capital	Land + Water + Technology + Labour + Capital	Current level
WS-NS	1672.0	1698.9	1734.5	1767.63	1767.63	1769.09	1769.09	3761.9
WS-BSLU	1672.0	1679.3	1734.5	1746.05	1746.96	1756.03	1756.03	3761.9
WS-BLUS	1672.0	1684.6	1734.5	1749.22	1750.19	1756.92	1756.92	3761.9
WS-BLUBS	1672.0	1672.0	1734.5	1734.50	1736.39	1745.17	1745.17	3761.9

Table 23. Minimizing Water use(in billion m^3)

Particulars	Land	Land + Water	Land + Technology	Land + Water + Technology	Land + Water + Technology + Labour	Land+ Water + Technology + Capital	Land + Water + Technology + Labour + Capital	Current level
WS-NS	18.24	18.24	18.24	18.24	18.24	18.24	18.24	24.73
WS-BSLU	18.24	18.24	18.24	18.24	18.24	18.24	18.24	24.73
WS-BLUS	18.24	18.24	18.24	18.24	18.24	18.24	18.24	24.73
WS-BLUBS	18.24	18.24	18.24	18.24	18.24	18.24	18.24	24.73

WS-NS =No sharing of water; WS-BSLU=Water sharing between season within the land units; WS-BLUS= Water sharing between land units within the season; WS-BLUBS= Water sharing between land units and between the season.

Objective : To develop future climate change scenarios for the study region through suitable statistical downscaling technique from the HADCM model run outputs.

HADCM3 climate change projections for Tamil Nadu region was downloaded and extracted from the GCM outputs of IPCC SCENARIOS.

Expected change in climate in 2020, 2050 and 2080 over 2000

Changes in rainfall, maximum temperature and minimum temperature during southwest and northeast monsoon in 2080 compared to 2000 indicated that the precipitation may increase by 10 to 15 per cent in all the six zones of Tamil Nadu during southwest monsoon season while, there may be a slight reduction in rainfall in the south western zone alone during northeast monsoon season. With respect to temperature, there is an increase of 2.5 to 5°C is expected in both the seasons and more increase is expected in minimum temperature compared to maximum temperature.

Objective: To calibrate and validate InfoCrop / DSSAT models for key food crops in different agroclimatic regions of Tamil Nadu.

Validation of Infocrop model
Infocrop model was validated for rice, maize and sorghum crop for Tamil Nadu region using the field experiments. The details are given below:

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

Treatment details : Genotype and Dates of sowing

A. Genotype

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

B. Dates of planting

D1 - 19th September (3rd week)
D2 - 26th September (4th week)
D3 - 3rd October (1st week)
D4 - 10th October (2nd week)
D5 - 17th October (3rd week)

Maize : The results of field experiment conducted to identify the best sowing window within the potential season for irrigated hybrid maize (CO H 3) at Tamil Nadu Agricultural University, Coimbatore during Kharif 2001 season was used for validation of Infocrop Model.

Treatment details: Dates of sowing

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

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

   A. **Main plot treatments (Times of sowing)**
          D_1 - June 8th, 2005
          D_2 - June 23rd, 2005
          D_3 - July 8th, 2005
          D_4 - July 23rd, 2005

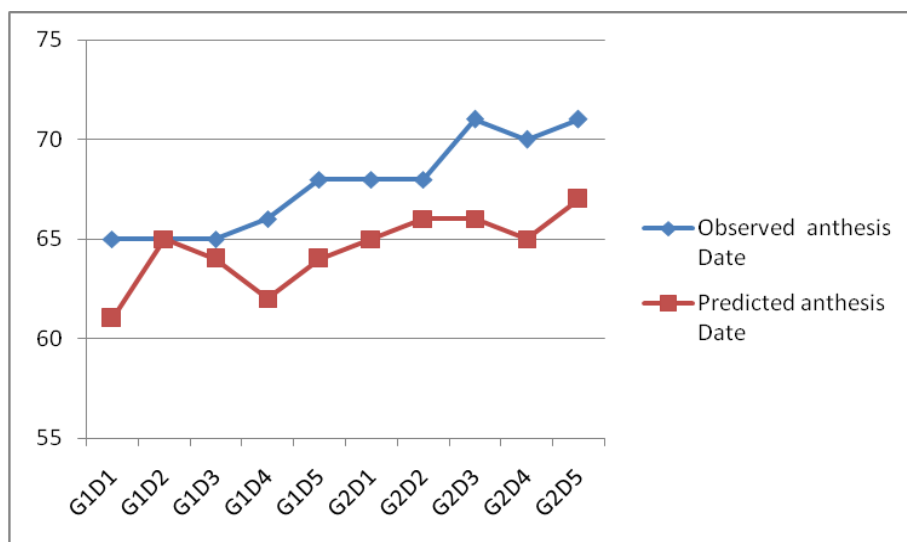   B. **Subplot treatments (nitrogen levels)**
          N_1 - 90 kg N ha^{-1}
          N_2 - 120 kg N ha^{-1}
          N_3 - 150 kg N ha^{-1}
 N_4 - Absolute control

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

i.   Rice

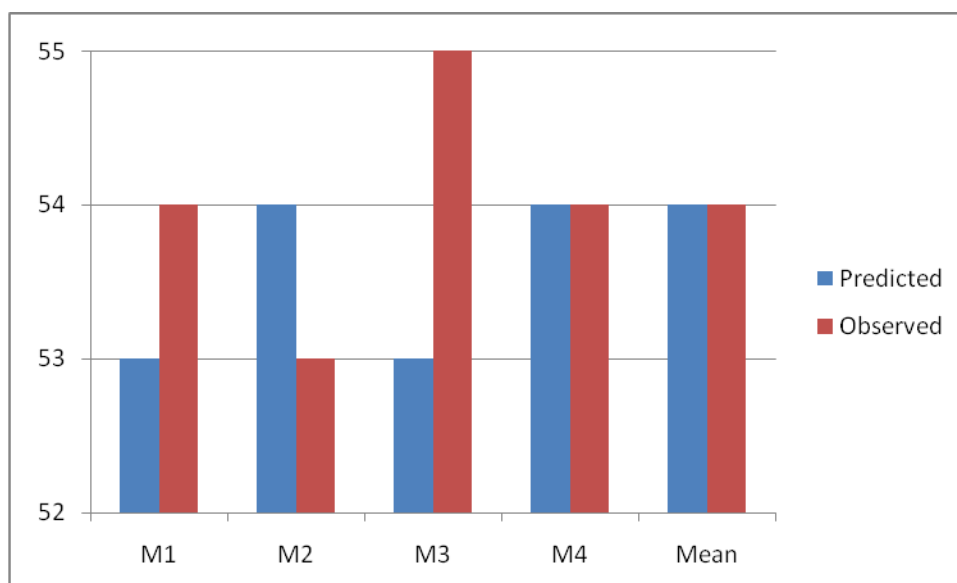**Fig: Observed and model predicted anthesis date for rice crop**

Anthesis date in both hybrid and rice variety were under predicted by 1 to 5 days in most of the cases. However, it exactly predicted in the hybrid when the crop was sown on 26th September.
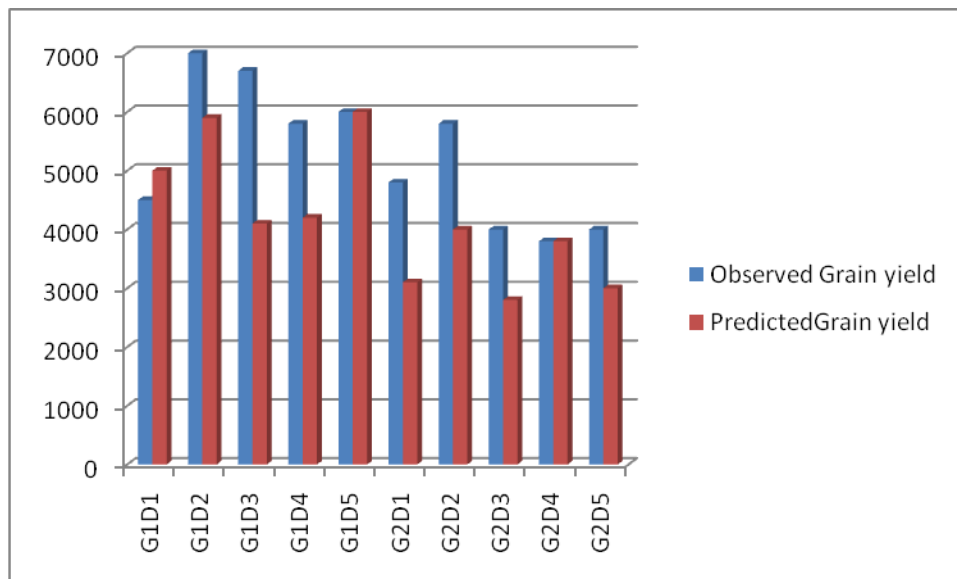
Fig: Observed and model predicted grain yield for rice crop

The model simulated the grain yield indicated both over estimation and under estimation of grain yield with different treatments. However, in most of the cases it was under estimated. There was no deviation in G1D5 and G2D4 treatments between predicted and observed grainyields. But the other treatments showed variation of more than 10 per cent.

ii.   Maize

Fig: Observed and model predicted teaseling date for maize crop

The results indicated that INFOCROP model predicted the date of tasseling closely to the observed values. The maximum deviation observed was two days between predicted and observed values.
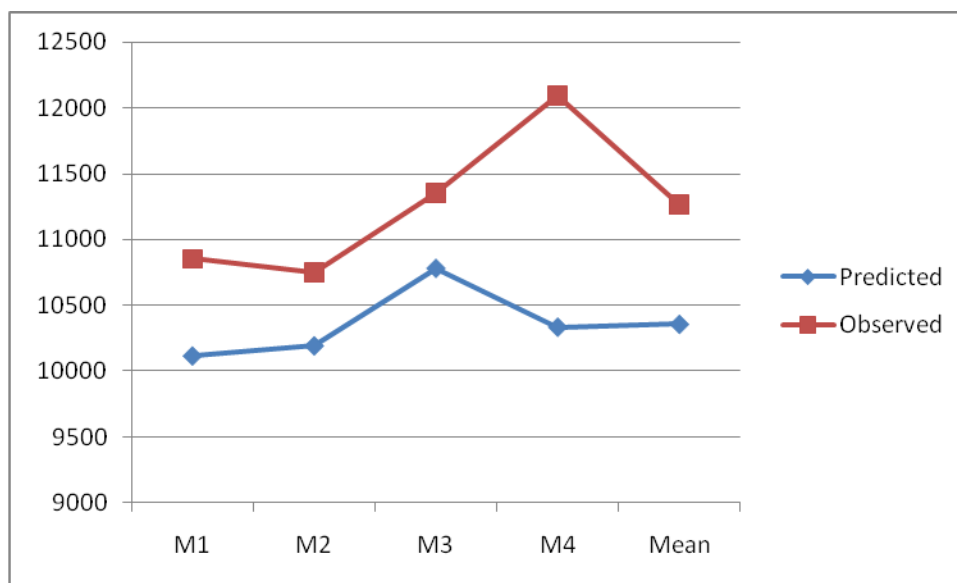
Fig: Observed and model predicted biomass yield (Kg/ha) of maize crop

The biomass yield was under estimated by the model, The difference between the observed and predicted values were high in the late sowing treatment (14 %). Mean biomass yield deviation between observed and predicted was 8 % in maize crop.
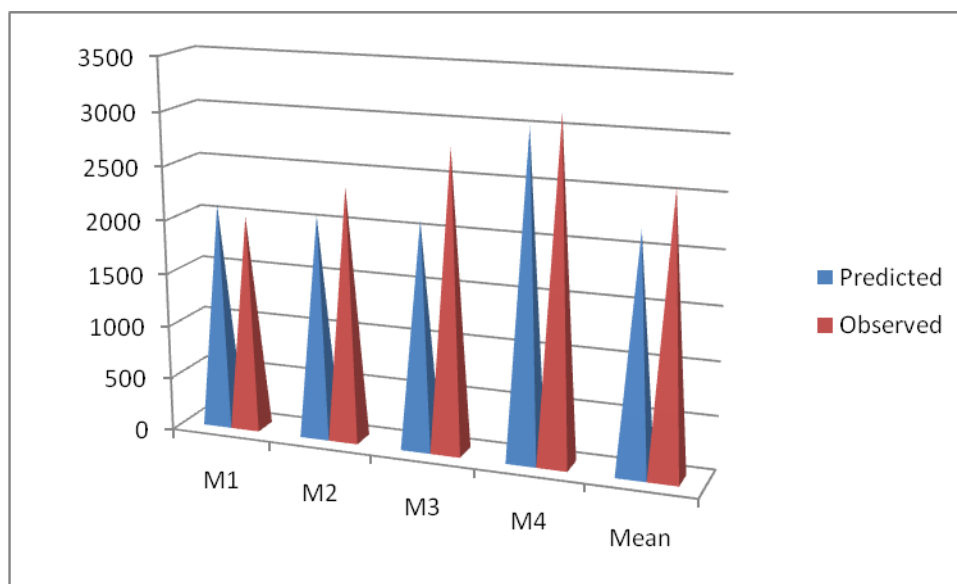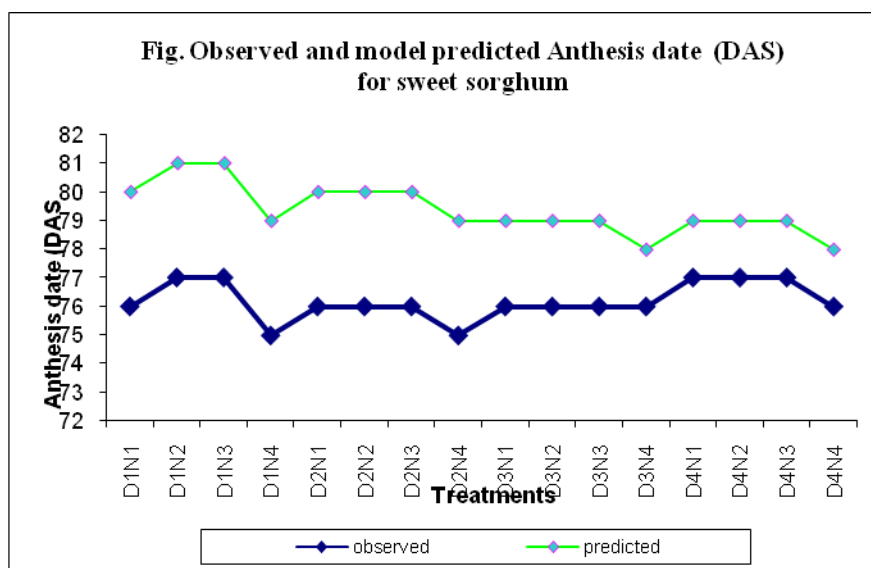

Fig: Observed and model predicted grain yield (Kg / ha) of maize crop

The model has well predicted the grain yield of maize, The difference between the predicted and observed grain yield was very less and with 5 % of deviation in M1 and M4 treatments

and was wider in M2 and M3 treatments. Mean grain yield deviation between observed and predicted was 14.8 % in maize crop.

iii.   Sorghum

The model predicted values of anthesis date closer to that of observed values. The difference between predicted and observed values was less than 10 per cent which indicated that the model predictions were within the acceptable limits.

Fig. Observed and model predicted Anthesis date (DAS) for sweet sorghum

The model predicted the mean biomass yield as 9053 kg ha^{-1}, while the mean observed biomass yield was 8141 kg ha^{-1} with lesser than 10 percentage deviation between the predicted and observed values indicating the fitness of the model.

Fig. Observed and model predicted Bio mass yield (kg ha-1) of sweet sorghum at harvest
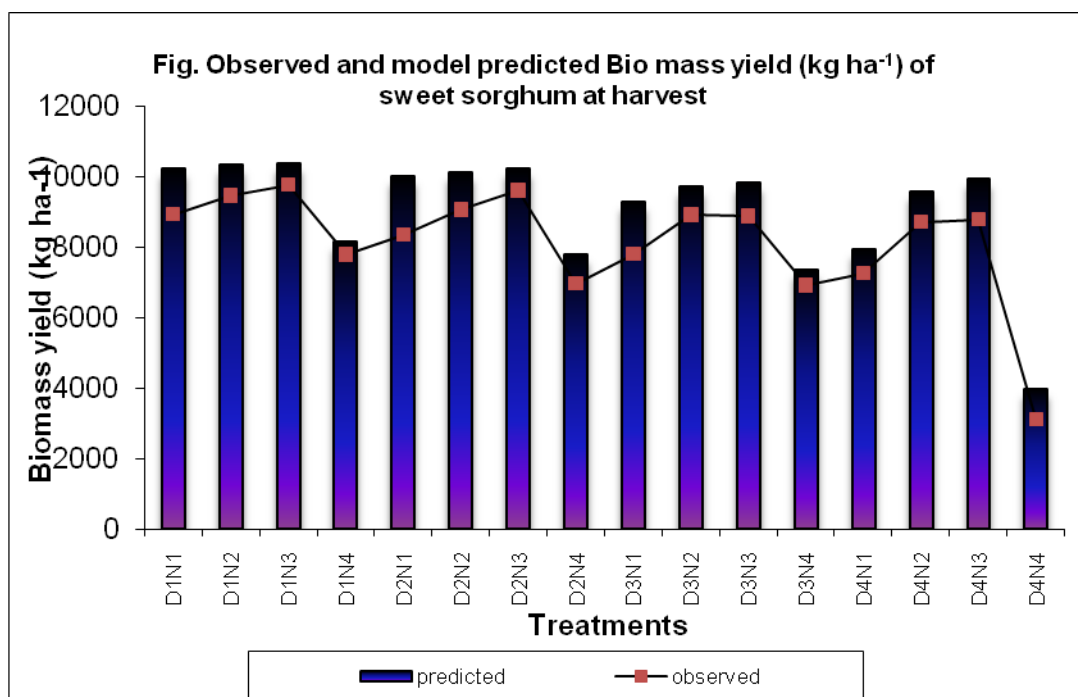
The grain yield was also well predicted. The mean observed grain yield was 1874 kg ha^{-1}, while the mean predicted grain yield was 1899 kg ha^{-1}. The percentage difference between predicted and observed values was lesser than 10 per cent for all the treatments.

Fig. Observed and model predicted grain yield (kg ha-1) of sweet sorghum
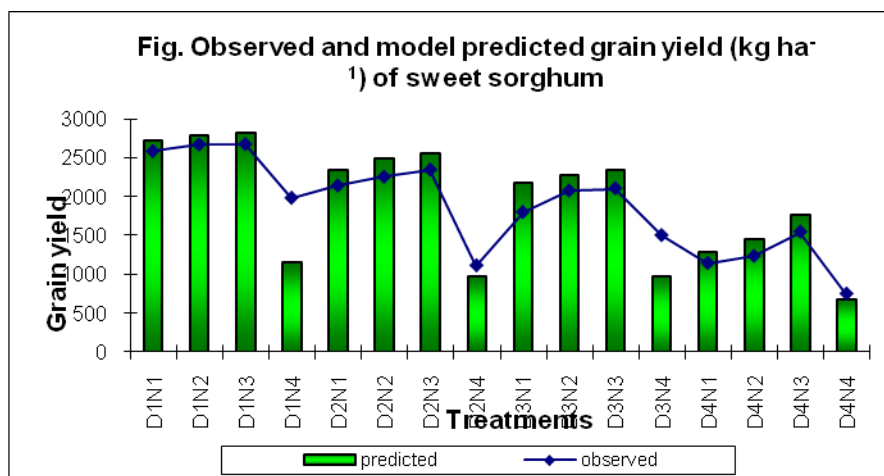
The reason for the correct prediction might be due to the efficiency of the model in predicting the phenological stages, growth and yield parameters with better accuracy levels (< 10 % difference). The model has also performed well in partitioning the photosynthates well between the total biomass and grain yield.

Objective: To quantify the impacts of different scenarios of climate change on key crops growth and production.

The results generated from the INFOCROP model for the Impact of climate change on rice, maize and sorghum productivity in the major crop growing districts over Tamil Nadu are presented in this section. The investigation results indicated the negative impact of climate change on all the three crops studied and the impact was more when the years progressed to 2050 and 2080 with more warming.
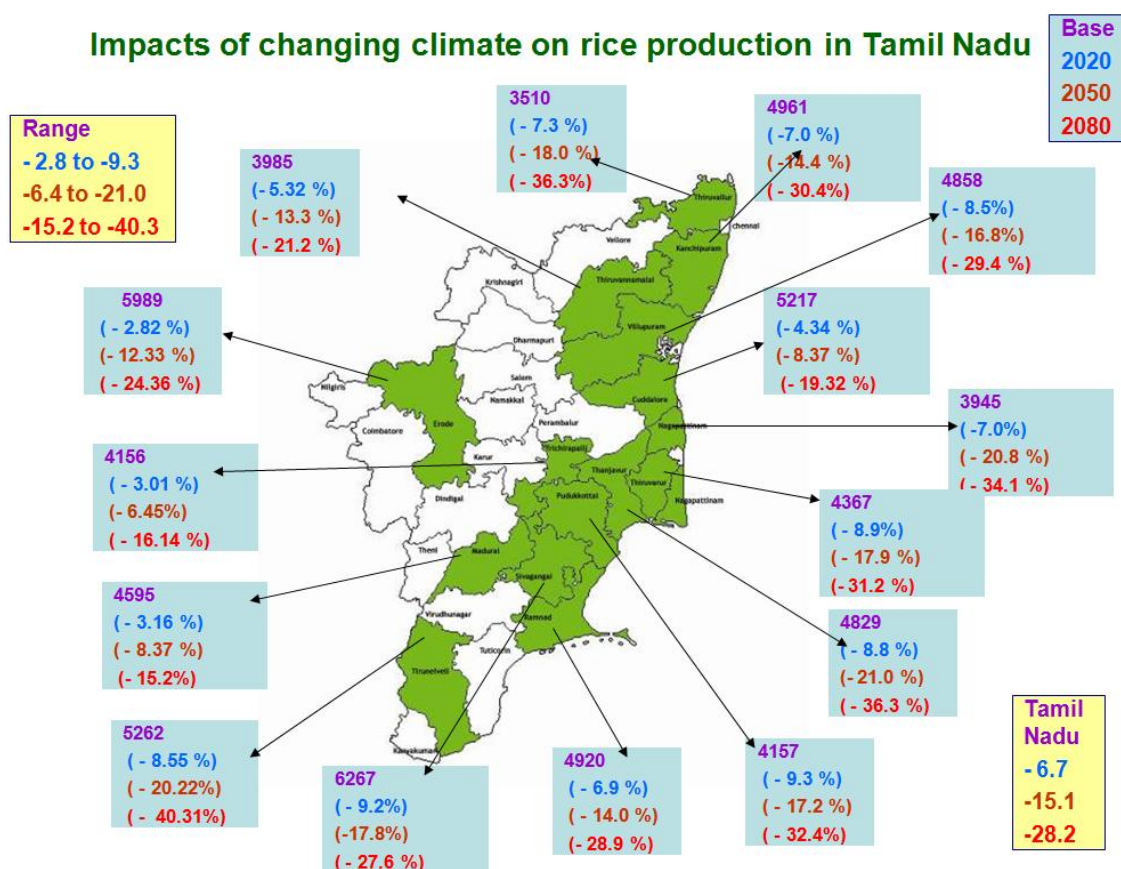
Among the three crops, more negative impact was observed with rice crop and the reduction in rice production is expected to be 6.7, 15.1 and 28.2 per cent in 2020, 2050 and 2080, respectively for the expected change in temperature, rainfall and CO_2 levels over Tamil Nadu region.

Impacts of changing climate on Maize production in Tamil Nadu

Base
2020
2050
2080

3992
(- 3.9 %)
(- 8.5 %)
(- 16.5%)

4575
(- 2.0 %)
(- 9.0 %)
(- 13.5 %)

4444
(- 1.7 %)
(- 6.7 %)
(- 15.0%)

4880
(- 3.0 %)
(- 7.5 %)
(- 16.9%)

4691
(- 1.9 %)
(- 8.8 %)
(- 24.1%)

4188
(- 2.9 %)
(- 7.4 %)
(- 18.1%)

5012
(- 3.0 %)
(- 10.4 %)
(- 19.8%)

3886
(- 2.1 %)
(- 10.5 %)
(- 19.2%)

4294
(- 6.2 %)
(- 15.0 %)
(- 21.4%)

Tamil Nadu
- 3.0
-9.3
-18.3

Range
- 1.7 to -6.2 %
-6.7 to -15.0 %
-13.5 to -24.1
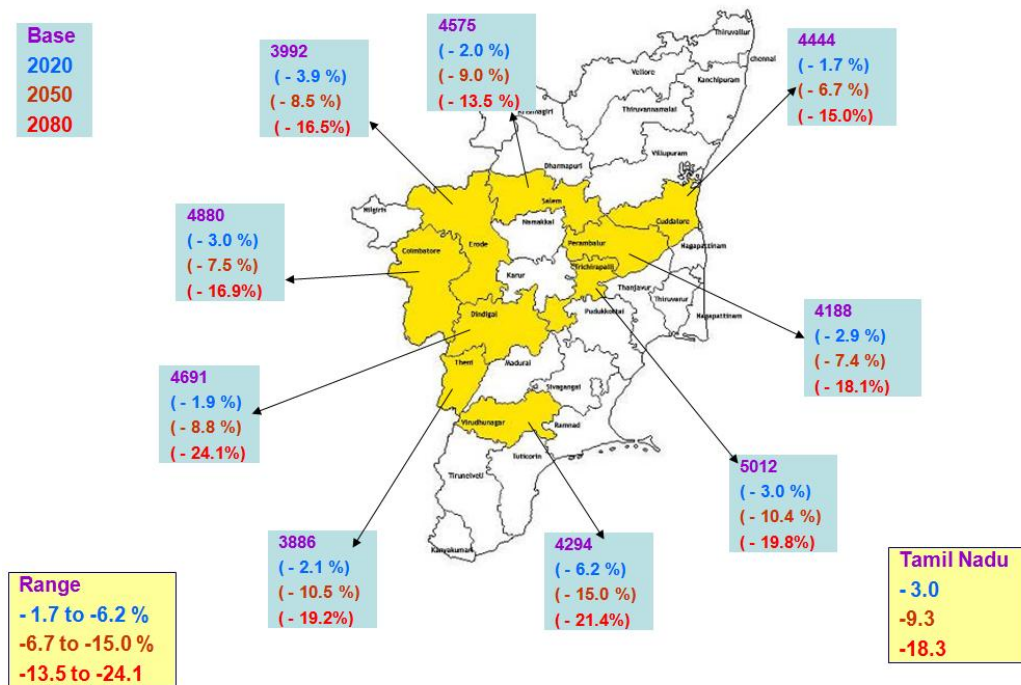
Analysis on the maize crop indicated reduction in yield by 3.0, 9.3 and 18.3 per cent respectively during 2020, 2050 and 2080 from the current yield levels in the major maize growing districts of Tamil Nadu.

Impacts of changing climate on Sorghum production in Tamil Nadu

Base
2020
2050
2080

Range
- 0.6 to -7.5
-8.2 to -15.1
-12.6 to -23.0

1215
(- 4.6 %)
(- 10.7 %)
(- 15.9 %)

596
(- 6.2 %)
(- 12.1 %)
(- 19.5%)

924
(- 3.1 %)
(- 9.0 %)
(- 18.3 %)

1029
(- 2.8 %)
(- 15.1 %)
(- 22.0 %)

301
(- 5.3 %)
(- 9.9 %)
(- 21.2%)

967
(- 6.1 %)
(- 14.7 %)
(- 17.7 %)

366
(- 0.6 %)
(- 9.0 %)
(- 12.6 %)

360
(- 2.4 %)
(- 8.8 %)
(- 13.2 %)

857
(- 1.5 %)
(- 8.2 %)
(- 20.6 %)

1078
(- 7.5 %)
(- 12.1 %)
(- 21.2 %)

Tamil Nadu
- 4.5
-11.2
-18.7

1494
(- 7.4 %)
(- 14.3 %)
(- 23.0 %)

687
(- 6.3 %)
(- 10.2 %)
(- 18.6 %)
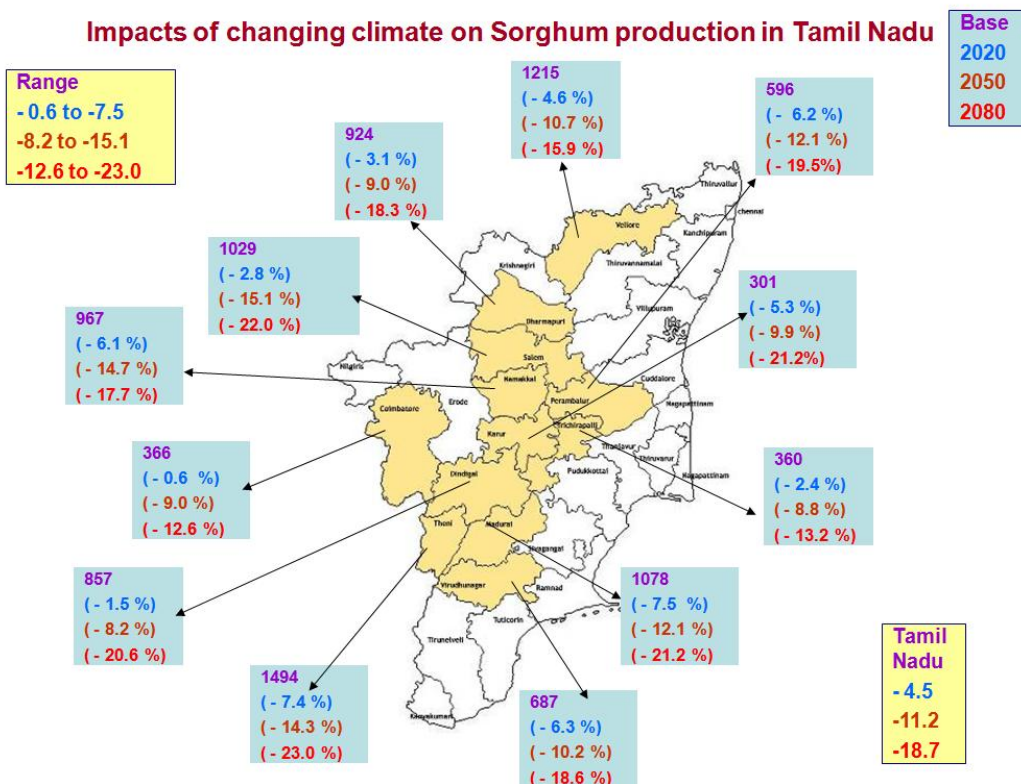
The results of sorghum crop revealed that the expected decline in yields is 4.5, 11.2 and 18.7 per cent respectively during 2020, 2050 and 2080 from the current yield levels if no management intervention is made in the major sorghum growing districts of Tamil Nadu. The yield reduction in all the three crops might be mainly because of more increase in night time temperature (minimum temperature) compared to the magnitude of increase in maximum temperature and variation in the expected rainfall.

Objective 5: To quantify the suitability of various agronomic measures for adaptation to climate change

Adaptation Assessment: Rice crop

Year	CO2 + Temp.	10 Days delayed planting	25% additional Nitrogen	No water stress	Increasing population by 20 %
2000	4563	4713	4626	4862	4482
2020	4166	4244	4336	4312	4159
2050	3485	3685	3748	3777	3925
2080	2637	2922	2855	2963	2785
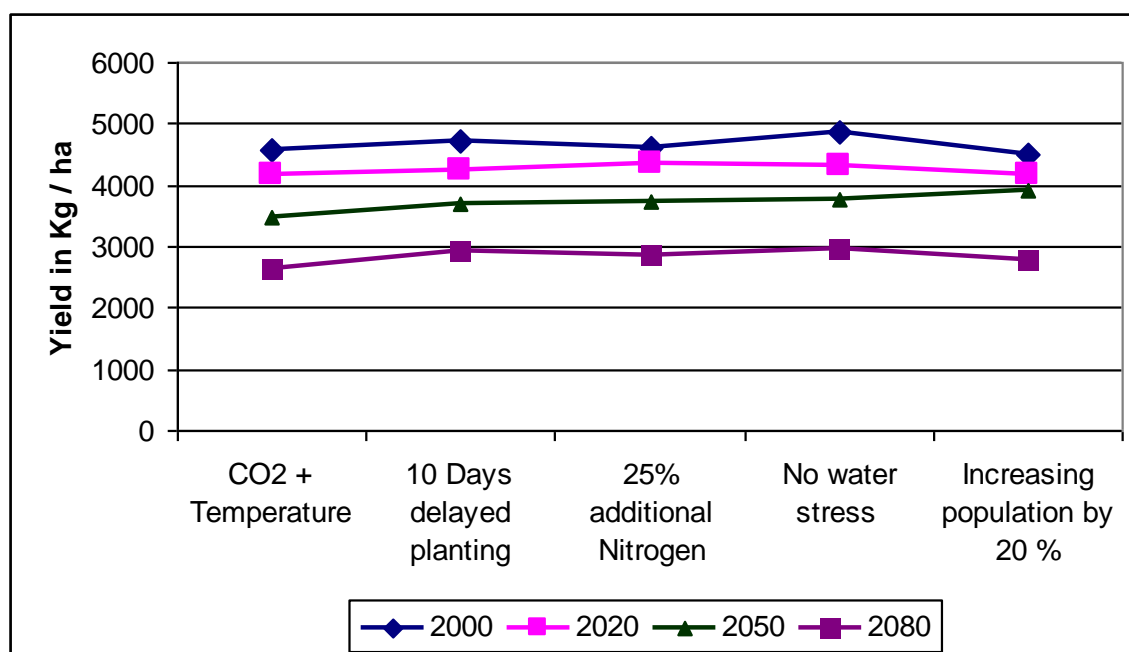
ANNEXURE 7: Papers published:

Central Plantation Crops Research institute, Kasargod

Naresh Kumar, S., Kasturi Bai, K. V. Rajagopal V. and Aggarwal, P.K. 2008. Simulating coconut growth, development and yield using InfoCrop-coconut model. Tree Physiology (Canada)-In press

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

ICAR Research Complex for Eastern Region,Patna

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

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

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

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

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

CENTRAL Marine Fisheries Research Institute, Cochin

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

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

1. **Participation in seminars**

2. Conducted ICAR sponsored Winter School "Impact of Climate Change on India Marine Fisheries" for 22 participants from Universities, colleges and ICAR Institutions for 21 days from 18.1.2008 to 7.2.2008 at CMFRI, Cochin.
3. Participated in the National Conference on climate change and made a presentation at NASC Complex, New Delhi on October 12 & 13, 2007.
4. Participated and presented a paper on Climate Change organized by Press Club of India on October 24, 2007 at Cochin
5. Participated and presented a paper "Issues in vulnerability assessment and adaptation in India" in the workshop organized by NATCOM Project Management Cell of MoE&F, Government of India on November 1 & 2, 2007 at New Delhi.
6. Participated and presented a paper "Environmental Issues and Capture Fisheries Sustainability" in the workshop organized by Cochin University on November, 16, 2007 at Cochin.
7. Participated and presented a paper "Climate change impacts in fisheries in Kerala" orgainsed by Kerala Agricultural University at Fisheries College, Panangad on December 14, 2007.
8. Participated and presented a paper Climate Change and Food Security with special reference to Marine Fisheries in the International Symposium conducted at CRIDA on February 18 & 19, 2008 at Hyderabad.

Tamilnadu Agricultural Reserch Institute, TNAU

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

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

Palanisami.K, C.Ranganathan, S.Senthilnathan and Chieko Umetsu, 2008. "Developing the Composite Vulnerability Index relating to Climate Change for the Different Agro Climatic Zones of Tamil Nadu", Inter-University Research Institute Corporation, National Institutes for the Humanities,

Research Institute for Humanity and Nature, Japan, Pp 127-137. ISBN: 978-4-902325-28-7

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

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

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

National Dairy research Institute, Karnal

R.C.Upadhyay, S.V.Singh, Ashok Kumar, Sandeep K. Gupta, Ashutosh, (2007). Impact of Climate change on Milk production of Murrah buffaloes. Italian J Anim. Science, **6,** (Suppl. 2), 1329-1332

R.C. Upadhyay, S.V. Singh, and Ashutosh (2008) Impact of climate change on livestock. *Indian Dairyman* **60(3):** 98-102.

C.Devraj and R.C.Upadhyay (2007) Effect of catecholamines and thermal exposure on lymphocyte proliferation, IL-1α & β in buffaloes, 8 th World Buffalo Congress, Caserta, Italy, Oct 19-22, 2007

R. C Upadhyay; Ashutosh and S.V. Singh (2007) Impact of temperature rise and climate change on growth and milk productivity of livestock. (Invited Paper) In: International Tropical Ecology Congress held at Dehradun, December 2-5, 2007. (Abstract) page 54.

R.C; Upadhyay, S.V. Singh, and Ashutosh (2008) Impact of climate change on livestock. *(Invited Paper)*: In: XXXVI Dairy Industry conference held at Banaras Hindu University, Varanasi (U.P.). Proceedings, PP. 68-73.

R.C. Upadhyay, A. Kumar, Ashutosh, S.V. Singh and S.K. Gupta (2007). Impact of climate change on milk productivity of Indian livestock. In: National

194

Conference on Impact of Climate Change with Particular Reference to Agriculture held at TNAU Coimbatore from August 22-24, 2007.

K.S.Roy and R.C.Upadhyay (2007) Methane emissions in expired air of buffaloes. International Tropical Animal Nutrition Conference, Volume II, Abstracts of the papers presented, October 4-7, 2007, NDRI, Karnal, Page 261.