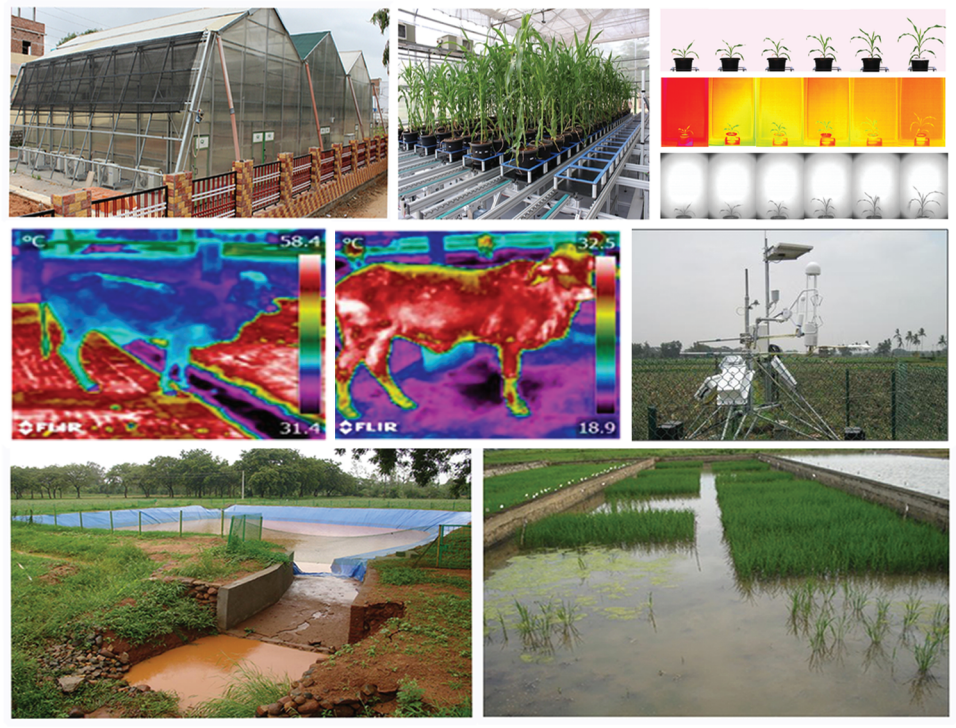
National Innovations on Climate Resilient Agriculture

Research Highlights 2014-15



NICRA

ICAR-Central Research Institute for Dryland Agriculture
Hyderabad - 500 059

Participating Institutes

Strategic Research

1. Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad including AICRPAM and AICRPDA
2. Indian Agricultural Research Institute (IARI), New Delhi
3. Indian Institute of Horticultural Research (IIHR), Bangalore
4. National Dairy Research Institute (NDRI), Karnal
5. Central Marine Fisheries Research Institute (CMFRI), Kochi
6. Central Institute of Agricultural Engineering (CIAE), Bhopal
7. ICAR Research Complex for NEH Region (ICAR-NEH), Umiam
8. National Research Centre on Plant Biotechnology (NRCPB), New Delhi
9. Central Rice Research Institute (CRRI), Cuttack
10. Indian Institute of Rice Research (IIRR), Hyderabad
11. Indian Institute of Pulses Research (IIPR), Kanpur
12. Indian Institute of Vegetable Research (IIVR), Varanasi
13. ICAR Research Complex for Eastern Region (ICAR-RCER), Patna
14. National Centre for Integrated Pest Management (NCIPM), New Delhi
15. Indian Institute of Water Management (IIWM), Bhubaneswar
16. Central Agro-Forestry Research Institute (CAFRI), Jhansi
17. Project Directorate for Farming System Research (PDFSR), Meerut
18. Indian Veterinary Research Institute (IVRI), Izatnagar
19. Central Inland Fisheries Research Institute (CIFRI), Barrackpore
20. Central Institute for Brackish Water Aquaculture (CIBA), Chennai
21. National Institute for Abiotic Stress Management (NIASM), Baramati

National Innovations on Climate Resilient Agriculture (NICRA)

Research Highlights (2014-15)

Compiled and Edited by

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ICAR-Central Research Institute for Dryland Agriculture

Hyderabad – 500 059.

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Contents

S.No.	Title	Page No.
Foreword		
Acknowledgements		
1.	**Background**	09
2.	**Objectives**	09
3.	**Project Components**	10
3.1	Strategic Research	10
3.2	Technology Demonstration	11
3.3	Knowledge Management (Portal Development) and Communication	12
3.4	Capacity building	12
4.	**Research Highlights**	13
4.1	Vulnerability and Impact Assessment	13
4.2	Agro-advisories for Farm Level Resilience	20
4.3	Resilience through Crop Improvement and Adaptation	30
4.4	Pest and Disease Dynamics and Pollinators	50
4.5	Adaptation and Mitigation through Soil, Water and Nutrient and Energy Use Efficiency	63
4.6	Impact and Adaptation Strategies in Livestock and Poultry	88
4.7	Impact and Adaptation Strategies in Fisheries	96
4.8	Socio Economic Impacts and Community Response	108
5.	**Technology Demonstration in Climatically Vulnerable Districts**	111

डा. एस. अय्यप्पन
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SECRETARY & DIRECTOR GENERAL

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FOREWORD

Climate change is one of the major challenges before Indian agriculture. The Indian Council of Agricultural Research (ICAR) responded to this challenge and launched the National Initiative on Climate Resilient Agriculture (NICRA) in the XI Plan. The major focus of the programme was on infrastructure development for strategic research, demonstration of best practices on farmers' fields to cope with climate variability, sponsored and competitive grant research and capacity building in the initial phase. During XII plan, NICRA is being implemented as National Innovations on Climate Resilient Agriculture.

NICRA has entered into a crucial phase of its implementation. The research outcomes of a few key thrust areas of this project are now evident in the form of products in pipe-line such as weather based insurance products, climate resilient crop genotypes, adaptation strategies with co-benefits of mitigation at farm and village level, microbes for adaptation and mitigation etc. The scheme has been strengthened with the inclusion of a few more crops and regions as well as expansion of technology demonstration to some more vulnerable districts. The research activities planned and implemented under NICRA are also well aligned with the goals of 5th assessment report of IPCC and will generate information on adaptation & mitigation in agriculture sector, and provide inputs to global fora like UNFCCC.

The major achievements of the project include micro-level agromet advisories to cope with seasonal climate variability, tolerant genotypes as well as a few advanced lines for climatic stresses in wheat, rice and pulses in multi-location testing stage, strengthened database of green house gas fluxes in various crops and agro-ecosystems, assessment of water and carbon foot prints and identification of climate resilient technologies with co-benefits of low global warming potential.

The technology demonstration component of the project, implemented through 121 KVKs across the country, identified appropriate location specific technologies that can enhance resilience to climatic variability. Successful demonstrations to cope with deficit rainfall situations, floods and cyclones were possible through implementation of climate focused action plans.

I compliment all the scientists involved in the project for developing well defined products and technologies for effective agricultural use and upscaling. I wish the project all success in the coming years and hope that it will fulfill the expectations of all stakeholders.

Dated the 5th August, 2015
New Delhi

(S. Ayyappan)

ACKNOWLEDMENTS

The formulation and launch of NICRA during the XI five year plan was made possible by help and guidance of a large number of senior officers of the Council. In the XII Plan, NICRA was strengthened with addition of strategic research partner institutes and expansion of technology demonstration to additional districts. The programme is now being implemented as National Innovations on Climate Resilient Agriculture. Dr S Ayyappan, Secretary (DARE) & Director General, ICAR and Secretary (ICAR) & Special Secretary (DARE) have played significant role in getting all the approvals for this major programme at various stages. Dr AK Sikka, Deputy Director General (NRM) was the driving force behind the successful implementation of this large programme involving several institutes and agricultural universities.

All the DDGs of ICAR and ADGs of the concerned SMDs have been providing their guidance through various stages of the project development and implementation. We are grateful to them. We also place on record our sincere gratitude to the expert technical committee for sponsored and competitive grants component led initially by Prof. YP Abrol and subsequently by Dr SM Virmani for guidance provided in screening, approval and review process of the projects.

The guidance and cooperation provided by Deputy Director General (Extn.) in development of action plans and implementation of technology demonstration component across 121 KVKs is gratefully acknowledged.

The senior officers of the NRM Division, Dr B Mohan Kumar, ADG (AAF & CC), Dr SK Chaudhari, ADG (SWM), other senior officers and staff have been extending their full cooperation in implementation of this programme and also in organizing several review meetings of high level committees in New Delhi. The Directors of all the participating Institutes have extended their full cooperation in the project implementation. A large number of farmers, State Department officials and public representatives have helped us in launching this programme across the country. We are indebted to all of them.

A multi-disciplinary team, other officers from CRIDA and scientists from participating institutes have put in their best efforts in overall coordination and implementation of the programme. We thank all them. I appreciate the efforts put in by the editorial team for bringing out this publication in time.

(Ch. Srinivasa Rao)
Director, CRIDA

National Innovations on Climate Resilient Agriculture (NICRA)

1. Background

Climate change has become an important area of concern for India to ensure food and nutritional security for growing population. To meet the challenges of sustaining domestic food production in the face of changing climate and generate information on adaptation and mitigation in agriculture to contribute to global fora like UNFCC, it is important to have concerted research on this important subject. The Government of India has accorded high priority on research and development to cope with climate change in agriculture sector. The Prime Minister's National Action Plan on climate change has identified agriculture as one of the eight national missions. With this background, ICAR launched a major project '*National Initiative on Climate Resilient Agriculture*' (NICRA) during XI Plan in February 2011.

Major aim of NICRA is to enhance the resilience of Indian agriculture, covering crops, livestock and fisheries to climatic variability and climate change through development and application of improved production and risk management technologies; to demonstrate the site specific technology packages on farmers' fields for adapting to current climate risks; and to enhance the capacity of scientists and other stakeholders in climate resilient agricultural research and its application.

2. Objectives

Considering that the climate change is a continued challenge, the focus on this critical area needs to be continued with greater emphasis. With this view, the scheme has been strengthened and efforts were made to build on the initiative taken during XI five year plan. Thus, National Innovations on Climate Resilient Agriculture (NICRA) is continuing with the following objectives.

- To enhance the resilience of Indian agriculture including allied sectors to climatic variability and climate change through development and application of improved production and risk management technologies.
- To demonstrate site specific technology packages on farmers' fields for adapting to current climate risks.

- To develop a knowledge management portal for dissemination of information to all stakeholders on climate change impacts on Indian agriculture.
- To undertake capacity building of different stakeholders

3. Project Components

Both short term and long term outputs are expected from the project in terms of new and improved varieties of crops, livestock breeds, management practices that help in adaptation and mitigation and inputs for policy making to mainstream climate resilient agriculture in the developmental planning. The overall expected outcome is enhanced resilience of agricultural production to climate variability in vulnerable regions. The project is comprised of four components.

1. Strategic Research through network as well as Sponsored/Competitive grants mode
2. Technology Demonstrations on farmers' fields to cope with current climate variability
3. Knowledge Management
4. Capacity Building of different stakeholders.

3.1 Strategic Research

In the strategic research, both short term and long term research programs with a national perspective have been taken up involving adaptation and mitigation covering crops, horticulture, livestock, fisheries and poultry.

The strategic research has been planned at leading research institutes of ICAR in a network mode covering crops, horticulture, natural resources management livestock and fisheries sectors.

The main thrust areas covered are (i) identifying most vulnerable districts/regions, (ii) evolving crop varieties and management practices for adaptation and mitigation, (iii) assessing climate change impacts on livestock, fisheries and poultry and identifying adaptation strategies. In the technology demonstration component, the available technologies with the National Agricultural Research System (NARS) to cope with climate variability are being demonstrated in 100 most vulnerable districts of the country selected across the country through Krishi Vigyan Kendras (KVK) and the Village Climate Risk Management Committees. The interventions are based on four modules, i.e., (i) crop production, (ii) resource management, (iii) livestock & fisheries, and (iv) institutional.

One of the major thrusts of the scheme was to build state of the art infrastructure for climate change research at core institutes. In particular, state of the art research facilities such as High Throughput Plant Phenomics facilities, FATE, CTGC, Eddy Covariance

Towers, a network of 100 Automatic Weather Stations, Animal Calorimeter, Research Vessel, etc. have been set up to support strategic research.

Significant achievements of the project during XI Plan include identification of promising lines for heat and drought tolerance in rice, wheat, maize, pigeonpea and tomato; quantification and techniques for measurement of GHG emissions in the rice-based system and marine ecosystem; quantification of carbon sequestration potential through agro-forestry systems across the country; preparation of first ever Vulnerability Atlas of India at district-level for all the 572 rural districts.

Considering the importance of climate change, this component of Strategic Research is continuing the focus on crops like wheat, rice, maize, pigeonpea, groundnut, tomato, mango and banana; cattle, buffalo and small ruminants among livestock and both marine and freshwater fish species of economic importance. Further, some of the theme areas have been strengthened which include phenotyping/breeding programs in crops, horticulture and livestock, simulation modeling to understand the impacts at regional/ national level, address crops and regions which could not be covered in the XI Plan such as onion, cotton, sugarcane, temperate horticulture, integrated modeling framework and network for GHG emission database. Hence, during the XII Plan, 19 additional partner institutes have been included under Strategic Research.

Sponsored and Competitive Grants

One of the key aspects of NICRA is sponsored/competitive grants. Research proposals addressing critical gaps not covered in the network project and highly location specific regional climate variability issues which have a major bearing on the productivity of principal crops in that region are being funded through this component. Eleven sponsored and twenty competitive grants projects which were initiated in earlier phase have been completed.

Critical researchable issues like germplasm collection from climate hot spots, impact on plant pollinators, fisheries in esturian habitats, hill and mountain ecosystem and socio-economic aspects of climate change, etc. were provided. In addition, impacts on certain economically important crops such as sugarcane, cotton were included.

3.2 Technology Demonstration

Under this component, participatory demonstration of climate coping technologies is being done on farmers fields. Improved practices like water harvesting, direct seeded rice, community nurseries, alternate wetting and drying, green manuring, deep placement of fertilizers and feed supplements for livestock are being demonstrated in 100 districts to cope with various climatic aberrations. The Technology demonstrations component is being expanded to 31 additional districts. Thus, participatory demonstrations of climate

coping technologies are being planned on farmers' fields in selected villages in 131 vulnerable districts of the country with interventions in NRM, crops, livestock and fisheries and farmers response and economic benefits are being documented. These demonstrations are quite successful and have attracted the attention of development department in several States and triggered the horizontal upscaling on a significant scale. As a part of institutional interventions, 100 custom hiring centres of farm machinery have been set up and this became the first pan-India pilot to promote small scale mechanization in the country.

3.3 Knowledge Management (Portal Development) and Communication

Since climate change and variability are growing subjects generating huge information on daily basis and a large number of stakeholders are involved in seeking/providing information and knowledge on climate change, a dedicated knowledge portal will be designed as knowledge portal on climate change and agriculture (KPCCA). This will be done partly by outsourcing through competitive bidding and also through internal cooperation among ICAR institutes and SAUs who have expertise in the field. Efforts are being made to develop the management portal which will act as a repository for all climate change related activities with latest information

3.4 Capacity building

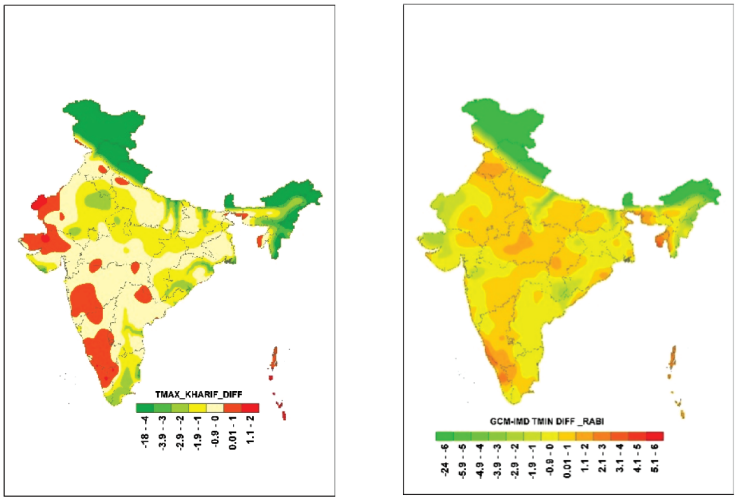
Under this component, need based training is being provided to farmers, extension personnel, research workers, scientists and other stakeholders.

4. Research Highlights

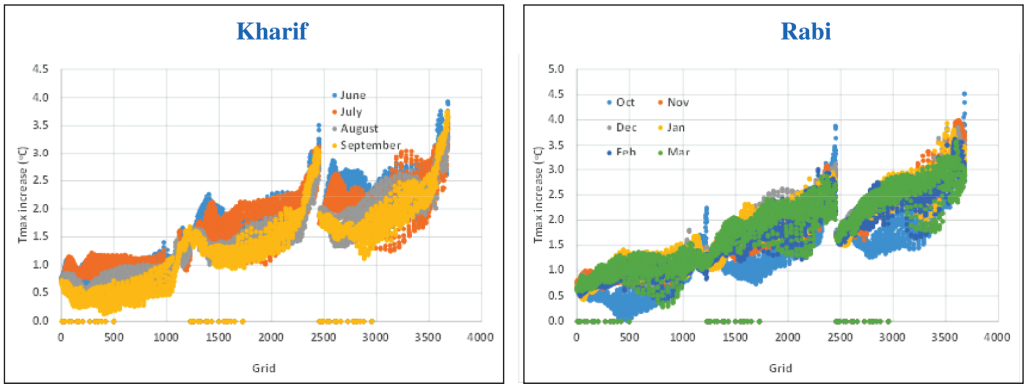
4.1 Vulnerability and Impact Assessment

Integrated assessments for adaptation gains (IARI)

In view of the recent scientific developments in climate science, agricultural modelling, and CMIP5 RCP based scenarios, the assessment of climate change impacts, adaptation and vulnerability will be done using the model ensembles and integration. For this, a spatial database on soils, weather and climate scenarios were developed. District-wise soils (Based on NBSSLUP data): total 1457 soil for 623 districts in India, incorporated into the InfoCrop v2.1 database 54 Global Climate Model outputs (0.5x0.5° gridded data, monthly) from 2005 to 2100 are downloaded. But based on the common and minimum data sets for running the models such as hydrological and crop models, 13 GCMs are selected and data were analysed.



RCP 4.5 Tmax



Projected changes in maxT and minT during *kharif* and *rabi*

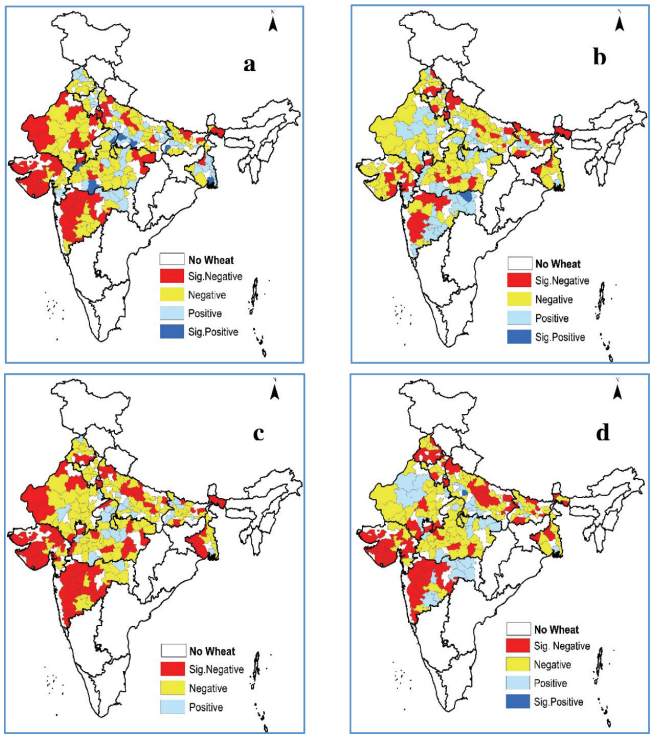
The GCMs have significant cold bias in the northern latitudes of India when compared with the IMD gridded data for baseline period (1980-2005) for minimum and maximum temperatures. In order to make the GCM scenarios usable bias correction was carried out and the resultant scenarios indicate significant warming of Indian region in future climates. For example, in RCP 4.5, the projected rise in maximum temperature is in the range of 0.2-1.7°C in 2020, 0.9-3.5°C in 2050 and 1-3.9°C in 2080 climate scenario for the kharif season. For *rabi* season, projected rise in maximum temperature varied from 0.10-2.3°C in 2020, 0.7-3.9°C in 2050 and 1.2-4.5°C in 2080 climate scenarios. Monthly variations were noted for projected rise in temperature. Maximum temperatures are projected to be more in northern latitudes and more during the *rabi* season.

As a part of the integrated assessments, climate change effects on crop yields are being assessed in Brahmani and Ramganga river basins. The rice yield is projected to be more unstable across the years in the Brahmani river basin in 2020 and 2040 climate scenarios in all four RCPs.

Sensitivity of Indian wheat yields to temperature: District level dynamics (CRIDA)

Wheat yields in major wheat growing districts were found to be inversely related to minimum temperatures (Tn) especially during post-anthesis period. Correlations were worked out between temperatures and wheat yields through AICRPAM net work centres across the country.

Among different months, Tn during February and January in considerable areas (79.2 and 86.7% area, respectively) showed negative association with district wheat yields. A regression of district yields for the period 1980–2011 on temperature variables (only for those districts where the correlations were negative and significant) resulted in a mean yield decline of 204 kg ha^{-1} with 1°C rise in Tn. Exposure to continual Tn exceeding 12 °C for 6 days and terminal heat stress with Tx exceeding 34 °C for 7 days during post-anthesis period are the other thermal constraints found in achieving high productivity.



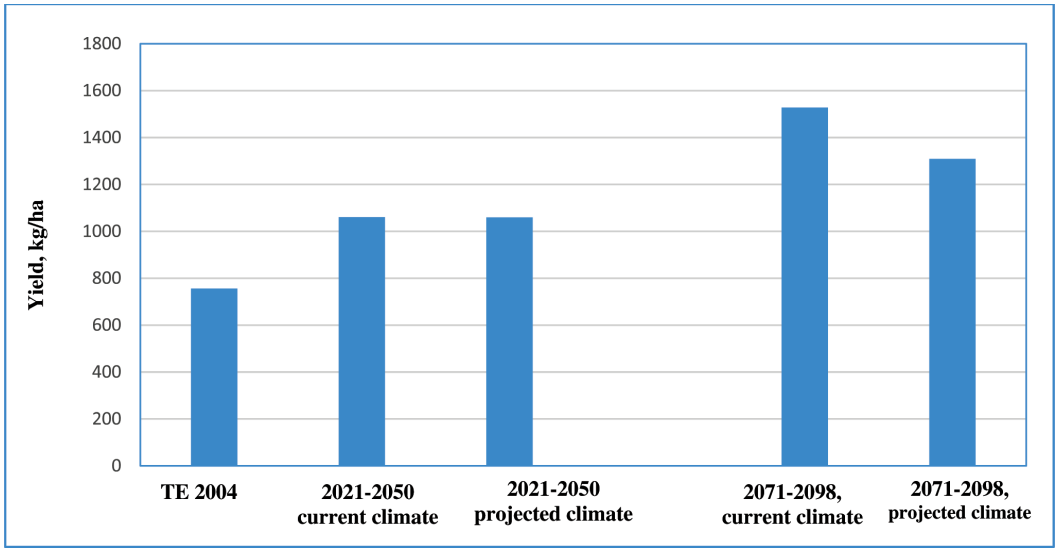
Correlation between (a) seasonal T_x; (b) February T_x; (c) seasonal T_n; (d) February T_n and district wheat yields

Vulnerability of sorghum and pearlmillet yields to climate change in India (CRIDA)

The GCMs has significant cold bias in the northern latitudes of India when compared with the IMD gridded data for baseline period (1980-2005) for minimum and maximum temperatures. In order to make the GCM scenarios usable, bias correction was carried out and the resultant scenarios indicate significant warming of Indian region in future climates. For example, in RCP 4.5, the projected rise in maximum temperature is in the rage of 0.2-1.7°C in 2020, 0.9-3.5 °C in 2050 and 1-3.9 °C in 2080 climate scenario for the Kharif season. For rabi season, projected rise in maximum temperature varied from 0.10-2.3 °C in 2020, 0.7-3.9 °C in 2050 and1.2-4.5 °C in 2080 climate scenarios. Monthly variations were noted for projected rise in temperature. Maximum temperatures are projected to be more in northern latitudes and more during the rabi season.

Vulnerability of a crop can be considered as probable fall in productivity because of climate change characterized by the changes in temperature and rainfall after accounting for the technological change. In other words, the changing temperature and rainfall will have adverse effect on crop yields but the technological advances may have some moderating effect on such reduction and the net effect can be considered as vulnerability of the yield of a particular crop to climate change. With this background, the vulnerability of productivity of sorghum, pearlmillet, in India was analyzed applying a panel data regression framework using the district level time series data for the period 1971-2004 on crop yield, monthly average temperature and rainfall and number of rainy days (June to November) in India. The variability in monthly temperature and rainfall was included in the model in the form of coefficient of variation (CV). A time trend variable to capture the technological trend was also included and the cross section dummies in the panel data regression would capture the district specific effects.

The model fitted was found to explain 58 and 69 per cent of variation in sorghum and pearl millet yields, respectively. The district specific effects were found to be significant in many districts. In case of sorghum, it was observed that average temperature during September and October were found to have a significant negative effect on productivity. Rainfall during June had a significantly positive effect and rainfall during September significantly negative effect on productivity. Using the climate data projected under A1 B Scenario (with PRECIS down scaling) for periods 2021-2050 and 2071-2098, the change in yield attributable to change in climate was estimated. It was observed that the yield effects were marginal during mid-century but substantial during the end-century period. There were also considerable spatial variation in the yield effects of climate change. During the end-century, the yield effects were found to be up to -100 kg/ha in 30 districts, between -100 to -200 kg/ha in 74 districts, -200 to -300 districts in 55 districts. In pearlmillet, the yield was projected to be about 274 kg/ha less than what would have been possible with the current yield trends.



Vulnerability of yield of sorghum to climate change

Distribution of districts based on projected changes in yield of sorghum during 2071-98 relative to 1961-90

Yield impact (kg/ha)	No. of districts
-400 to -301	13
-300 to -201	55
-200 to -101	74
-100 to 0	30
Total	172

Enhancing resilience to climate variability and change in watersheds with focus on groundnut and pigeonpea in the Indian SAT (ICRISAT)

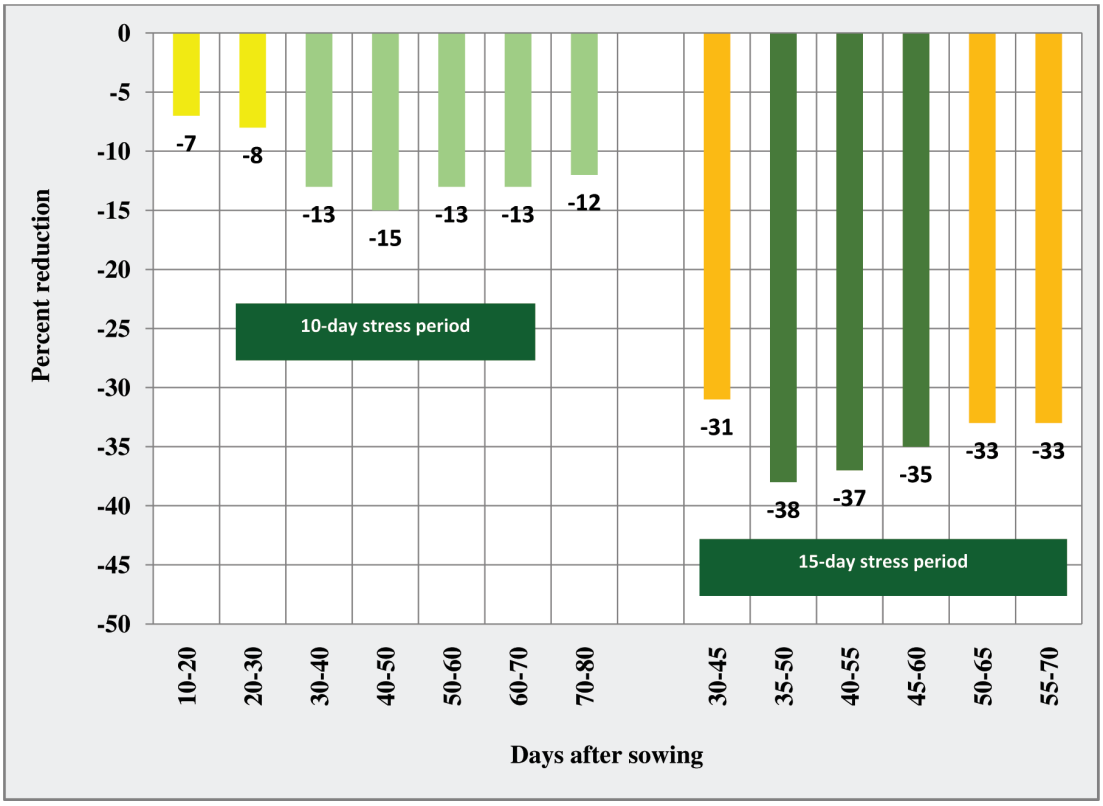
The uncertainty of the rains is one of the major constraints for rainfed groundnut production. Similarly pigeonpea is an important semi-arid legume crop in India and is mostly grown in Karnataka, Maharashtra and Andhra Pradesh on Vertisols.

The daily observed weather data of ICRISAT Patancheru for 30 years (1985-2014) and the DSSAT PnutGRO model were used to identify the critical water stress period for groundnut. Genetic coefficients for the groundnut variety ICGV 91114 were derived from the field experimental data. Groundnut ICGV 91114 and pigeonpea TS 3R cultivar coefficients were derived from the field experimental data of 2011 and validated with data of 2012.

The impacts of water stress on groundnut for both 10-day and 15-day periods were studied using the PnutGRO model.

Results indicated that a 15-day water stress period 40-60 days after sowing would reduce yields significantly. If the water stress in this period is not properly managed, groundnut yields could be reduced by about 33 per cent of the rainfed potential yields.

Current conditions (interpolations of observed data, representative of 1950-2000) and downscaled GCM data from the Coupled Model Inter-comparison Project Phase 5 (CMIP5) 17 for three models (HadGEM2-ES, GFDL-CM3 and CNRM-CM5) were downloaded from the WorldClim - Global Climate Data portal and representative data were extracted for the study location i.e., ICRISAT, Patancheru. These climate projections are for RCP 8.5 and for the year 2050 (2041 to 2060).



Impact of water stress on groundnut pod yield

Simulations with projected climate data (HadGEM2-ES, GFDL-CM3 and CNRM-CM5) indicated that groundnut pod yield would reduce by 9 to 13 per cent.

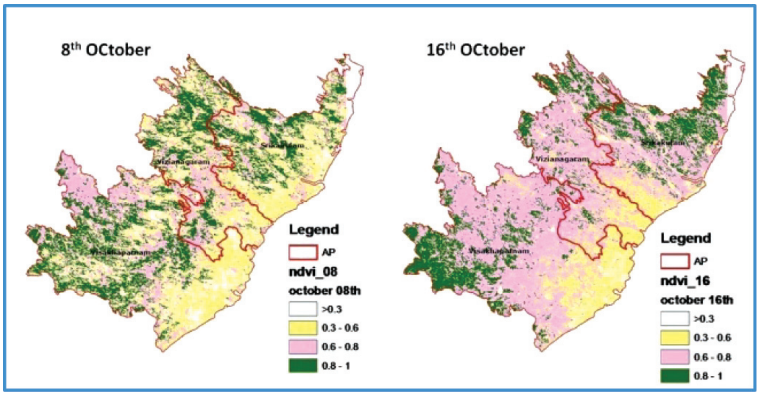
Impacts of projected climate on groundnut and pigeonpea yields at ICRISAT

Climate change scenario	Pod/ seed yield (kh/ha)	Change in pod/ seed yield (%)	Total dry matter production (kg/ha)
Groundnut on Alfisols			
Current	2000	-	5430
HadGEM2-ES	1820	-9	5410
GFDL-CM3	1830	-9	5350
CNRM-CM5	1750	-13	5250
Pigeonpea on Vertisols			
Current	2280	-	10380
HadGEM2-ES	2320	2	10650
GFDL-CM3	2030	-11	9340
CNRM-CM5	2370	4	10810

The crop genetic coefficients for the pigeonpea variety TS 3R were derived from the NICRA field experiments conducted at ICRISAT, Patancheru. The APSIM pigeonpea crop-growth simulation model was used to assess the impact of projected climate on productivity. Pigeonpea simulations indicated that pigeonpea yields would reduce by about 11 per cent under the GFDL-CM3 projected climate scenario. In both the crops, simulation results indicated more runoff which is likely to lead to more soil erosion and nutrient loss.

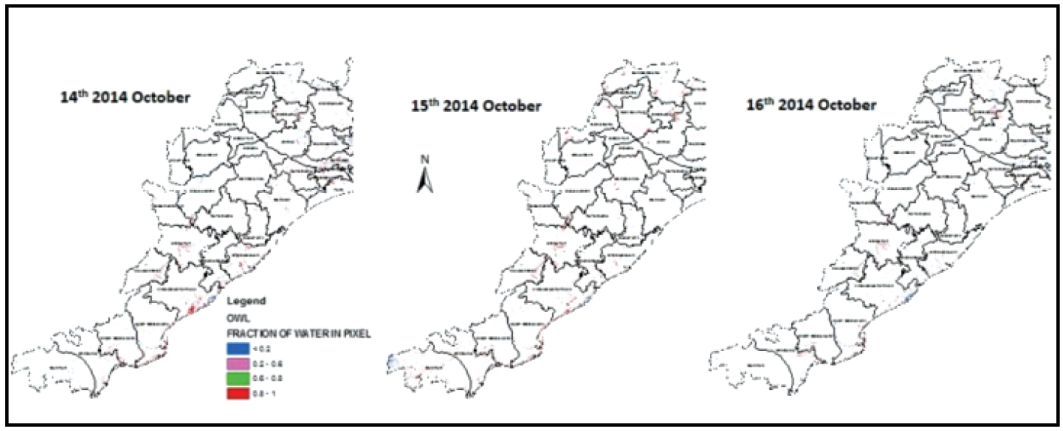
Monitoring the impact of extreme weather events (CRIDA)

During the year 2014-15, though seasonal and annual was less than normal in the country, different states witnessed cyclones, unseasonal rains during kharif and rabi seasons affecting seasonal crops and horticultural crops. The Hudhud cyclone during October, 2014 caused severe damage to existing horticultural crops and rice crops in north coastal districts of Andhra



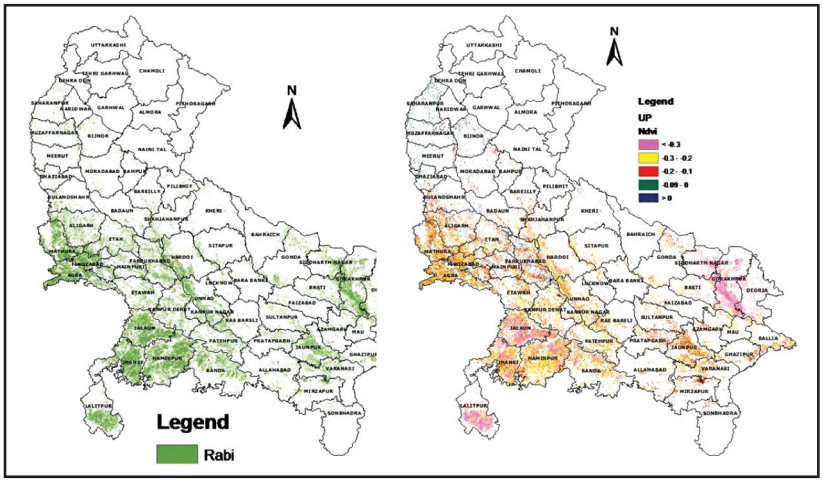
Monitoring of vegetation through NDVI-Hudhud cyclone

Pradesh and Orissa. An attempt was made to understand the damage by using remote sensing information. Parameters such as Normalised Difference Vegetation Index (NDVI) and Open water Likelihood index (OWL) were used to assess the change in vegetation and extent of flooding respectively. Public domain data available through MODIS was utilised for the analysis.



Monitoring of flooded areas through MODIS data- Open Water Likelihood (OWL) Index

During *Rabi* season unseasonal rains affected rabi crops particularly wheat, mustard in North India due to which the production targets could not be met. The rains were widely spread in the country from Jammu & Kashmir to Andhra Pradesh and spread over from February to April. Due to these rains, severe lodging of crop was seen in fields. The difference in NDVI was observed between the pre and post rainy events. The normal growing areas information available from Bhuvan/NRSC was considered for analysis to identify the difference in NDVI for crop damage assessment. The analysis was carried out for Uttar Pradesh, Rajasthan and Haryana. Large scale difference in NDVI values could be attributed to crop harvesting. Small scale decrease in NDVI values could be attributed to crop damage and the same was depicted spatially for Uttar Pradesh, Rajasthan and Haryana.



Changes in NDVI – During Feb and March 2015 – Uttar Pradesh

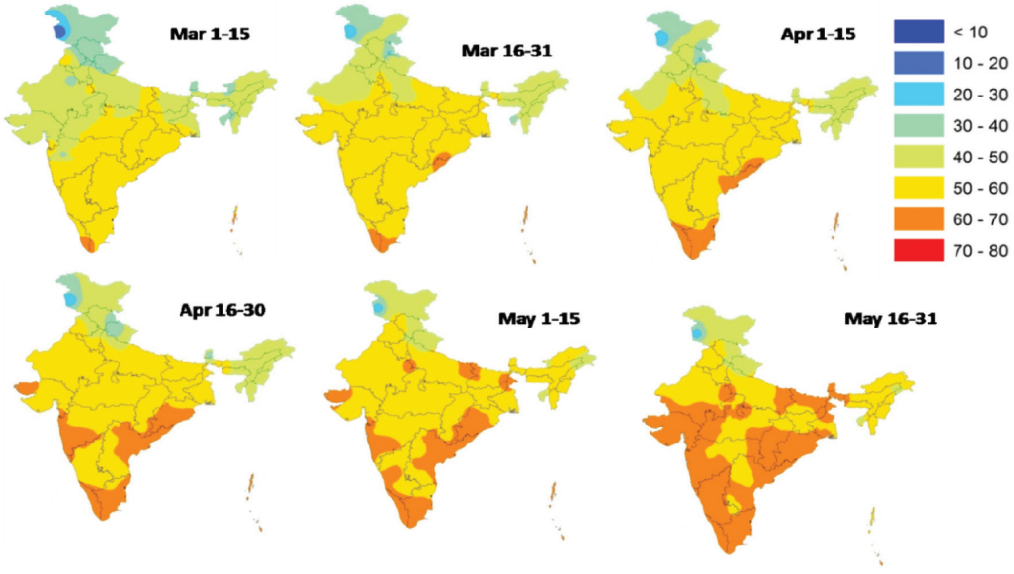
4.2 Agro-met advisories for farm level resilience (CRIDA)

Weather data acquisition and value addition

Real time collection of weather data and its interpretation in relation to crop grants are key to generate timely agromet advisories to focus. To achieve this 100 automatic weather stations (AWS) have been installed across the country under NICRA project. Regular weather and crop data are being collected from all these locations. During 2014-15 systematic validation of AWS data was conducted at several locations.

Data received with no missing(s) and no sensor problems were considered as quality data. Everyday quality checking of 100 locations was carried out and about 91 weather stations out of 150 AWS generated quality data during 2014-15. Online real time weather data watching / download provision was made through the website-www.aicrpam-nicra-aws.in. From the web statistics it was inferred that about 5,00,000 users are regularly watching /downloading the data.

Real-time weather data from 100 AWS stations were used to generate spatially interpolated products using ArcGIS. Number of heat wave/cold waves was identified along with their severity. The Dairy Heat Load Index (DHLI) is a new index to quantify the risk of heat stress on grazing dairy cattle and it takes into account temperature, relative humidity, effect of wind speed and amount of solar radiation and quantifies the heat load. DHLI was estimated during fortnightly interval for summer months viz., March, April and May 2014.



Dairy Heat Load Index (DHLI) during summer months of 2014 across India estimated using AWS data

Weather indices in two crops for different districts

Weather indices viz. triggers and exit in wheat and groundnut for major wheat and groundnut growing districts were worked out by analyzing their long-term yield data in relation to phenophase-wise weather conditions. These indices are essential for designing district level weather insurance products in wheat and groundnut.

Wheat

Weather indices in wheat were developed for three districts i.e. Hisar, Karnal and Sirsa of Haryana and five districts of Uttar Pradesh viz. Faizabad, Jhansi, Kanpur, Lucknow and Varanasi. The maximum or minimum temperature required for above average, average and below average yield were named as trigger 1, trigger 2 and exit, respectively. In Haryana, for trigger 1 maximum temperature at same critical stage (Anthesis to Dough stage) varied from 26.0 to 27.0 °C and minimum temperature varied from 9.8 to 11.3 °C, across districts Sirsa and Hisar. However, for exit both maximum and minimum temperatures vary from 27.9 to 30.1 °C and 11.3 to 14.3 °C, respectively across these districts. In Uttar Pradesh, in four out of the five districts, milk to dough stage was identified as the critical stage for temperature and for trigger 1 and exit, maximum temperature varied from 25.3 to 26.4 °C and 27.1 to 28.2 °C, respectively across the four districts. However, variation in minimum temperature for trigger 1 and exit across the districts is higher and it is 8.4 to 11.1 °C for trigger 1 and 11.1 to 13.9 °C for exit.

Weather indices in major wheat growing districts of Haryana and Uttar Pradesh

State	District	Critical stage	Max T (°C)			Min T(°C)		
			Trigger 1	Trigger 2	Exit	Trigger 1	Trigger 2	Exit
Haryana	Hisar	Anthesis to dough	27.0	27.5	30.1	9.8	10.5	11.3
	Karnal	Ear emergence to anthesis	20.7	21.9	22.4	6.8	8.9	9.8
	Sirsa	Anthesis to dough	26.0	27.2	27.9	11.3	11.5	14.3
Uttar Pradesh	Faizabad	Milk to dough	25.8	26.5	27.1	8.4	10.4	11.1
	Jhansi	Anthesis to milk	23.4	25.0	26.0	7.1	7.4	8.9
	Kanpur	Milk to dough	25.3	25.4	27.6	9.6	11.1	12.4
	Lucknow	Milk to dough	25.5	26.3	28.2	9.1	11.1	12.5
	Varanasi	Milk to dough	26.4	26.5	27.5	11.1	12.1	13.9

Groundnut

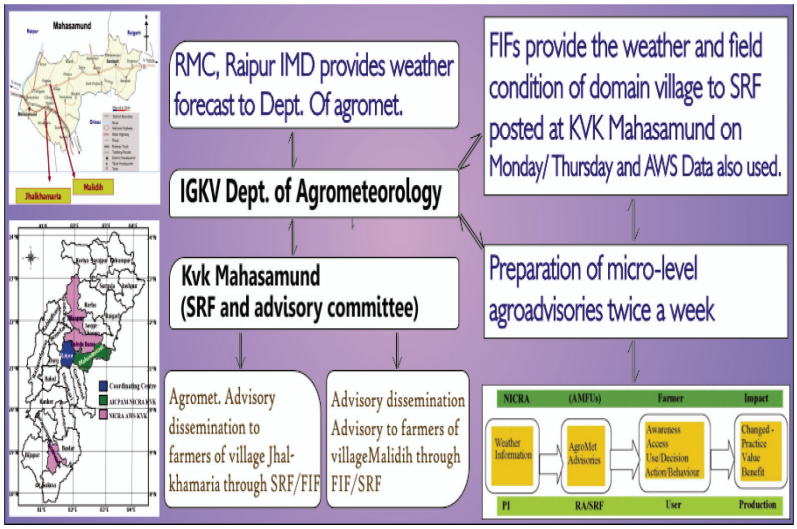
Rainfall indices in groundnut were formulated for three districts viz. Bangalore (rural), Dharwad and Bijapur of Karnataka and eight districts viz. Junagadh, Jamnagar, Rajkot, Amreli, Bhavnagar, Kutch, Sabarkanta and Banaskanta of Gujarat. In Karnataka, critical stage for rainfall differed from district to district and as a result rainfall and rainy days for trigger 1, trigger 2 and exit differed among districts. In Gujarat, first peg to first pod was identified as the critical stage for rainfall in Rajkot, Amreli and Bhavnagar districts and rainfall in this common critical stage varied from 145 to 240, 40 to 64 and 13 to 29 mm, respectively for trigger 1, trigger 2 and exit across the three districts. At Banaskanta and Sabarkanta, 50% flowering to first peg was the critical stage and rainfall varied from 114 to 231, 78 to 110 and 1 to 17 mm for trigger 1, trigger 2 and exit, respectively at these two districts.

Indices of rainfall and rainy days during critical growth stages of groundnut in major groundnut growing districts of Karnataka and Gujarat

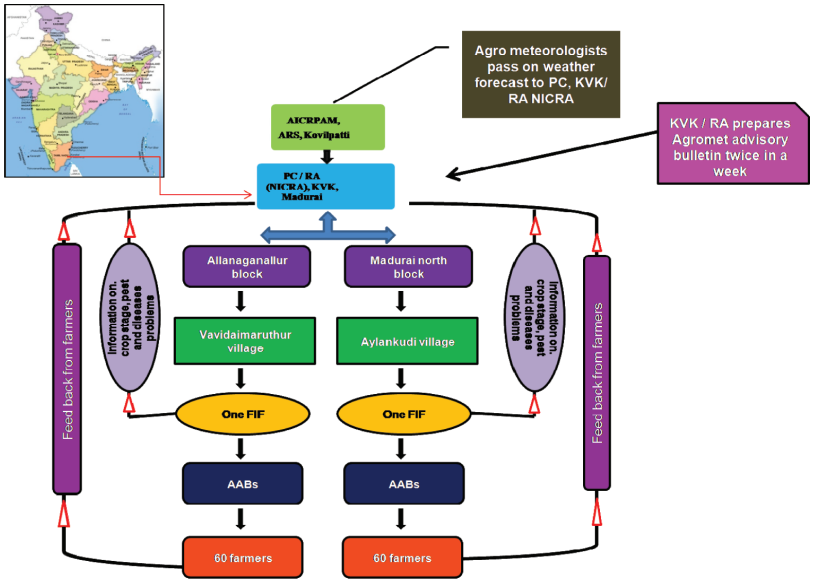
State / District	Critical stage	Rainfall (mm)		
		Trigger 1	Trigger 2	Exit
Karnataka				
Bangalore (rural)	50% Flowering to pod initiation	152 (7)	125(6)	60 (4)
Dharwad	50% Flowering to pod filling	268 (10)	171(9)	109 (7)
Bijapur	Pod initiation to pod filling	199 (9)	75(5)	64 (4)
Gujarat				
Junagadh	First seed to harvest	338 (18)	188 (12)	83 (9)
Jamnagar	50% Flowering to first pod	552 (13)	182 (9)	24 (2)
Rajkot	First peg to first pod	240 (7)	45 (4)	13 (2)
Amreli	First peg to first pod	175 (7)	40 (4)	29 (1)
Bhavnagar	First peg to first pod	145 (10)	64 (5)	21 (3)
Kutch	First pod to first seed	245 (7)	35 (2)	8 (1)
Sabarkanta	50% Flowering to first peg	231 (6)	110 (5)	1 (0)
Banaskanta	50% Flowering to first peg	114 (5)	78 (4)	17 (1)

Micro-level Agromet advisories

A major objective of AICRPAM-NICRA project is the customization of micro-level Agromet advisories and their dissemination through Information Communication Technologies (ICTs). Raipur center has formed a dissemination system which involves IMD block level weather forecast, Field information Facilitators (FIFs') information about field conditions, Agromet department of IGKV Raipur, KVK of Mahasamund and farmers, the end user. Procedures involved in preparation and dissemination of micro-level AAS is depicted in the flowchart.



The AAS development and dissemination system developed by Raipur center



Flowchart of AAS dissemination system developed by Kovilpatti center

The AAS development and dissemination adopted by Kovilpatti center is represented. The important feature of all these systems is the same - there is a field information facilitator (FIF), who communicates the status of crop growth, other information related to cultivation in the NICRA village to KVK. This micro-level information helps to prepare more accurate AAS bulletins by Program Coordinator, KVK.

Economic impact of Agromet Advisory Services

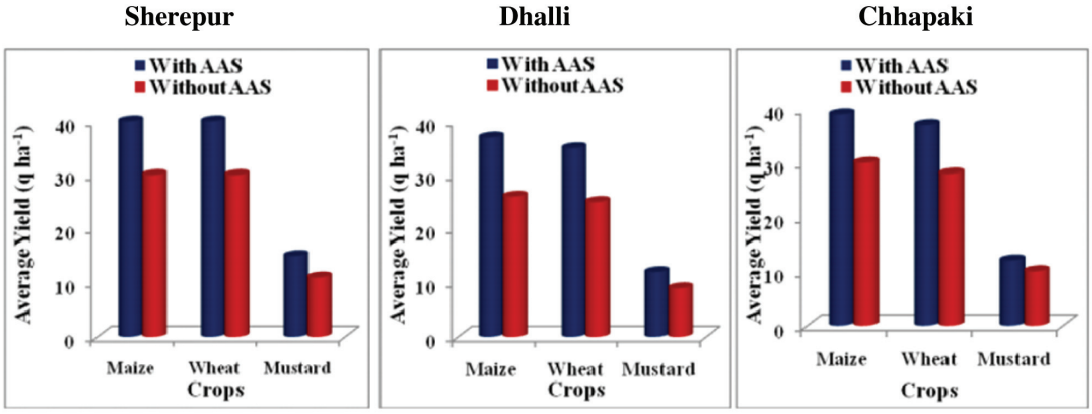
Some of the benefits accrued due to adoption of AAS across different villages under various AICRPAM-NICRA centres are presented below.

Economic impact of Agromet advisory services (AAS) at villages adopting AAS in four states of India

Weather based AAB issued on	Forecasted weather	Advisory given	Advisory followed	Economic Benefit
Karnataka				
06-10-14	Forecast of moderate rainfall	Postpone the spray schedule in grapes	Yes	Saved Rs.1,500/acre
13.12.14	Forecast of light to moderate rains	Postpone the pesticide sprays in grapes	Yes	Saved Rs. 3,500/acre
Dec 9th 2014	Forecast of moderate rainfall: 11mm	Harvest maize immediately the crop and store in safe place	Yes	Benefit: Rs 6000 /acre
Uttar Pradesh				
24-9-2014	Forecast of no rainfall	To give irrigation to rice crop	Yes	Benefit of Rs.1500/ha
Andhra Pradesh				
11-06-2014	Rainfall forecast : 30-70mm	Postpone irrigation in Jasmine	Yes	Benefit of 400/- per acre

Weather based AAB issued on	Forecasted weather	Advisory given	Advisory followed	Economic Benefit
27-10-2014	Rainfall forecast : 0-15mm	Postpone harvesting of Kharif maize	Yes	Benefit of 7,500/ ha
25-11-2014	Rainfall forecast : 25-90mm	Postpone harvesting of Fox tail millet	Yes	Loss of 1600/- ha
Jammu & Kashmir				
21/01/2014	Rainfall forecast : 6 mm	Postpone the irrigation, harrowing,	Yes	Benefit: Rs. 1400/- ha
21/01/2014	Rainfall forecast : 6mm	weeding and fertilizer application in	Yes	Benefit: Rs.900/- ha
04/02/2014	Rainfall forecast : 17mm	wheat & mustard	Yes	Benefit: Rs.1200/- ha

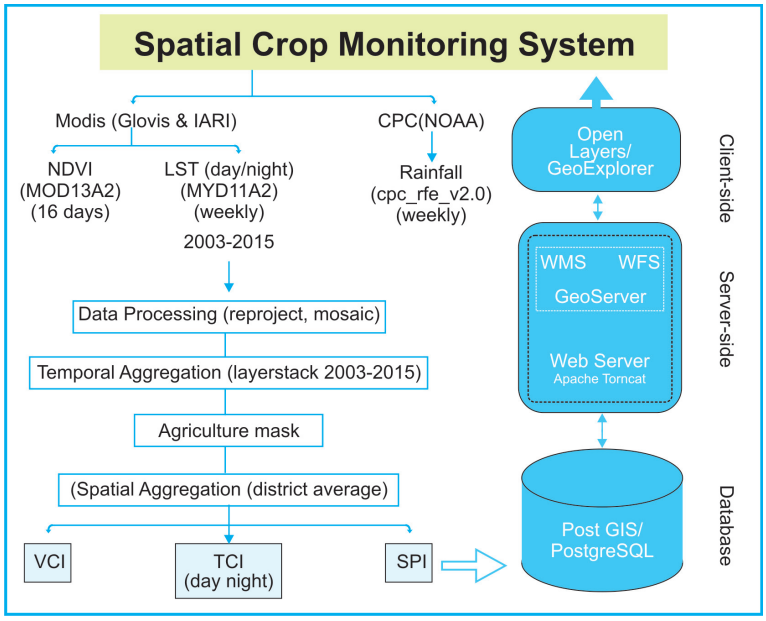
The Jammu center compared the yields of maize, mustard and wheat crops of farmers those who followed and not followed AAS in Sherepur, Dhalli and Chhapaki villages, and farmers who followed AAS registered significantly higher yield than the non AAS farmers in all the crops.



Comparison of yield in different crops with and without following AAS at Sherepur, Dhalli and Chhapaki village, Jammu & Kashmir

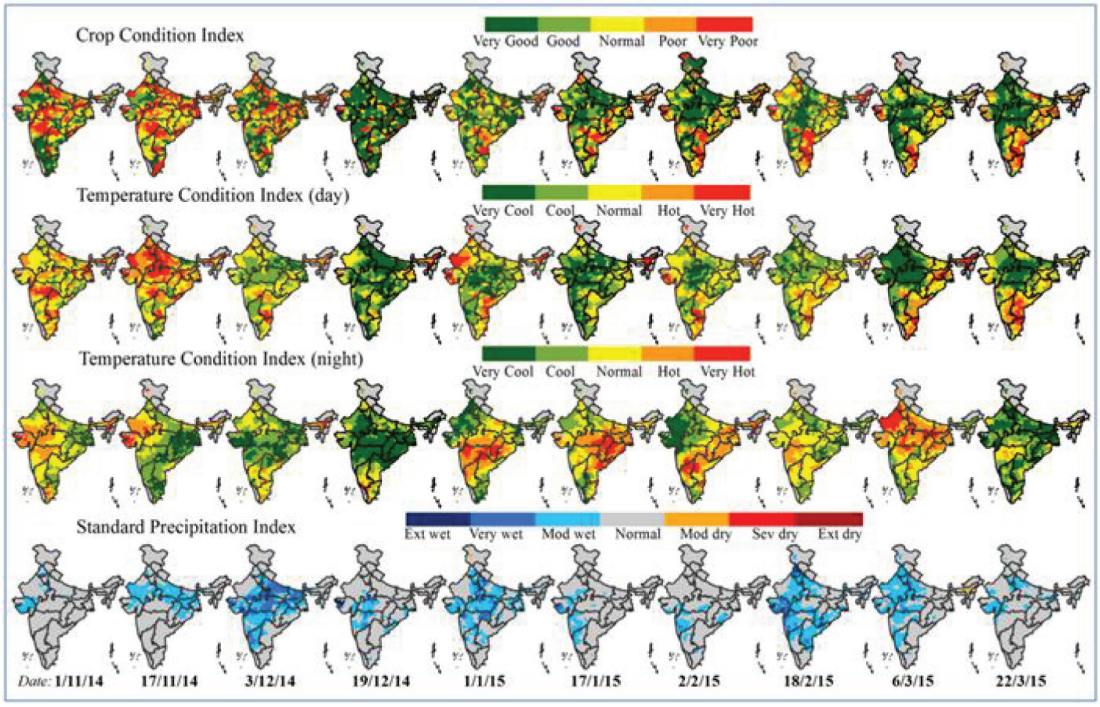
Crop monitoring system and its applications (IARI)

Design, development and application of a web enabled decision support system (DSS) for near real time crop monitoring at district level and making the information available to different stakeholders for building resilience of agriculture to weather variability was taken up at IARI. The system used multi-temporal remote sensing images received at IARI satellite ground station. Three-tier architecture was implemented on web-portal using open source Web GIS – the data is imported and stored in PostGIS/PostgreSQL in tabular form. The server-tier includes Apache web server, PHP and Geoserver. Open layer is used for visualization of geospatial data for client application.



Flowchart of spatial crop monitoring system and its web-portal architecture

Regular near real-time satellite derived parameters of rainfall, day and night land surface temperature (LST), and crop vigour index of NDVI were generated for crop pixels and aggregated at district level. Using historical values, weekly anomaly indices of standardized precipitation index (SPI), Temperature Condition Index (TCI) and Crop Condition Index (CCI) were generated for each of the 579 districts of India. The historical and real-time basic parameters and anomaly indices are archived in a database and can be accessed through a public web portal http://creams.iari.res.in. The portal allows visualization of SPI, CCI and TCI as categorized maps for current period and over the crop season. Besides these maps, for a selected district, the portal shows the temporal profile of parameters of a selected district for current year and it compares with the profile of previous year as well as long term average in graphical and tabular format. The parameter database is kept updated with new real time data and the system was used to monitor crop condition and crop environment parameters for 2014-15 season. Seasonal CCI, TCI and SPI maps corresponding to rice growing district and wheat growing district at the end of kharif and rabi seasons, respectively, were also produced.



Crop condition index, temperature condition index (day and night) and standard precipitation index maps of India for Rabi 2015 season

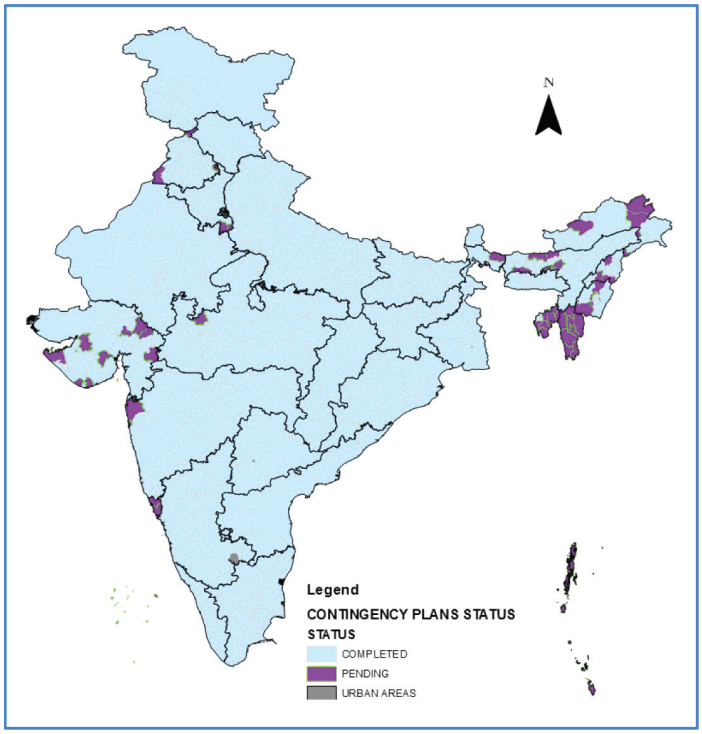
The periodic and seasonal maps of SPI could clearly pick-up the developing of meteorological drought conditions in central India during June-July 2014. Similarly, it clearly captured the districts receiving unseasonal rainfall during March 2015. The TCI (day) showed that major parts of India remained hot while TCI (night) showed that it remained hot to very hot during the Kharif season. Based on VCI, the crop condition was found to be poor in some districts of western Uttar Pradesh (Bundelkhand), southern Andhra Pradesh and western Tamil Nadu during Kharif 2014-15. The information provided as maps and time-series graphs of parameters can be used by local agencies in improving their agro-advisories.

Updating District Level Agriculture Contingency Plans (CRIDA)

Contingency plans at district level for all the 126 agro-climatic zones of the country to deal with weather related aberrations such as droughts, floods, heat wave, cold wave and pest outbreaks etc., covering crops, livestock and fishery sectors based on the available research information were previously prepared and made available for 600 districts in the country on ICAR/DAC websites (http://farmer. gov.in/, http://agricoop.nic.in/acp.html, http://crida.in/ and to all state agriculture departments. These contingency plans contain information on crop varieties and alternate crops to be chosen in case of delay in onset of

monsoon or early season drought and also on agronomic measures for mid and terminal season droughts.

Efforts are being made to update these district contingency plans with more recent information on suitable verities for drought, floods and other agronomic measures emanating from national agricultural research systems and also from component of Strategic Research and Technology Demonstration of NICRA. During the year 2014-15, interface meetings with state agricultural universities were held at *Vasantrao Naik Marathwada Krishi Vidyapeeth (*VNMKV*), Parbhani* for Marathwada region of Maharashtra, Acharya NG Ranga Agricultural University (ANGRAU), Tirupati for Andhra Pradesh, ICAR-NEH Complex, Barapani, Shillong for North East states, Junagadh Agricultural University for Saurashtra of Gujarat, IGKV,Raipur for Chhattisgarh states. For other states, efforts on to update these contingency plans.



Status of District Contingency Plans

Real-time contingency plan implementation (CRIDA)

Contingency crop plans to cope with weather aberrations were implemented on real time basis through 23 centres of AICRPDA. Salient successful interventions are presented below:

Delayed onset of monsoon: At Kavalagi village (Bijapur district, Karnataka), the onset of monsoon was delayed by 28 days. Introduction of improved varieties of pigeonpea (TS-3R), pearlmillet (ICTP-8203), mothbean (KBMB-1), horsegram (GPM-6) and groundnut (DH-101) gave 37, 24, 19, 27 and 22% higher yield over local/ farmers' varieties of respective crops.

At Kalimati/Dholiya village (Banaskantha district, Gujarat), under delayed onset of monsoon by 25 days, pearlmillet hybrid GHB 558 (75-85 days) recorded significantly highest seed (1265 kg/ha) and fodder (2937 kg/ha) yields, over local variety (MH 179).

Under delayed onset of monsoon by 14 days, at Chamua village (Lakhimpur district, Assam), the short duration varieties of rice (Luit, Kolong, Dishang and Lachit) gave 25 to 50% higher yield over local varieties, where as the medium duration varieties (TTB-404, Mohon and Mulagabharu) gave 46 to 64% higher yield over farmers' varieties.

Early season drought: At Bhdhadani village (Kandhamal district, Odisha), mulching with crop residues in turmeric (Cv. Lakdong) gave 31% higher yield than unmulched crop (6500 kg fresh rhizomes/ha).

At Aminabad village (Kurnool district, Andhra Pradesh), intercultivation in groundnut with tractor drawn intercultivator gave higher pod (489 kg/ha) and haulm (1145 kg/ha) yields than farmers' practice (450 kg/ha and 1024 kg/ha) with higher net returns (Rs. 2970/ha) and B: C ratio (1.12).

At Warkhed village (Akola district, Maharashtra), *in-situ* moisture conservation with furrow opening at 30 DAS in soybean resulted in higher seed yield (1021 kg/ha) with net returns of Rs. 12428/ha and B:C ratio of 1.63 compared to no conservation furrow (847 kg/ha).

Mid-season drought: At Pata Meghapar village (Jamnagar district, Gujarat), two supplemental irrigations from harvested rainwater to cotton at flowering and boll formation stages, recorded 42% higher seed cotton yield with net returns of Rs.58650/ha, B: C ratio of 2.80 and RWUE of 5.74 kg/ha- mm compared to no supplemental irrigation.

At Ningnoti village (Indore district, Madhya Pradesh), *in-situ* soil moisture conservation with plastic mulching in soybean gave 35% higher seed yield (955 kg/ha) with net returns of Rs.17659/ha and B:C ratio of 2.61 compared to no mulching. Similarly, foliar spray of thiourea @ 250g/ha at vegetative and early flowering stage of soybean gave higher seed yield of 964 kg/ha, with net returns of Rs.17929/ha compared to no foliar spray.

Terminal drought: At Chamua village (Lakhimpur district, Assam), one supplemental irrigation along with mulching in potato gave highest tuber yield of 26748 kg/ha with net return of Rs. 87216/ha.

4.3 Resilience through Crop Improvement and Adaptation

Development of crops and varieties adapted to climatic stresses is an important activity under NICRA. To address this objective, major food and horticultural crops are being evaluated for tolerance to abiotic stresses (drought, heat, flooding, salinity). Work on genetic enhancement has been carried out in a multi-institutional and multi-disciplinary network mode during the year. Wheat, rice, maize, pigeonpea, mango and tomato are being focussed by the partner institutes.

Phenotyping of wheat germplasm for physiological, agronomic and morphological traits under drought and heat stress (IARI)

Increase in the rate of yield improvement can be achieved by targeting traits that affects yield in dry and warm environments. The variability among the international core set under Indian conditions alongwith an Indian germplasm set was explored and selected some promising lines as donors for breeding programmes. The genetically diverse core set and Indian set was analysed under rainfed/restricted irrigation conditions to screen for drought stress and under delayed planting for heat stress. Genotypes with higher stomatal conductance (Gs) and cooler canopies under warmer climate were identified. Genotypes have been selected from Indian and international core set for various physiological traits pertaining to drought and heat tolerance and are being used as donors in breeding programmes to introgress heat and drought tolerant traits.

Phenotypic evaluation of selected and improved lines under drought and heat stress

The backcross derived lines with more than 90% recurrent parent background recovered in BC_1F_1 and BC_2 F_1 progenies were selfed and carried forward for development of homozygous lines. The selfed BC_1F_2 and BC_2F_2 homozygous lines are advanced for seed multiplication and homogeneity phenotyping. MARS was exercised for drought and heat tolerance by conducting multi-location phenotyping at four target locations (IARI New Delhi, ARI Pune, JNKVV Powarkheda and PAU, Ludhiana) under rainfed and irrigated conditions in two F_4 base biparental populations comprising of 160-180 lines.

New QTLs were identified among the F_4 base populations by employing marker-trait associations. The best progenies were selected on the basis of multi-location data and genotyping with SSR markers linked to stress adaptive traits. For combining favorable QTLs, stress adaptive traits like early vigour, SPAD values at vegetative and reproductive stage, canopy temperature at vegetative and reproductive stage, NDVI, chlorophyll fluorescence, flag leaf area etc. were assessed in two base populations. Inter-family intermatings among the best identified families were carried out in F_5 generations in different combinations to accumulate and recombine 4-8 QTLs per intermated progeny. The progeny of F5:2 and F5:1 X F5:1 hybrids were screened for genetic homogeneity and enhanced WUE and/or heat tolerance. Finally the homozygous intermated lines were screened phenotypically in field trials to identify best lines to be released as varieties.

Evaluation of wheat advanced lines for drought tolerance

Total of 45 advanced lines derived from cross between DBW 43 × HI 1500, VL755/ UP2338//BAU/KAUZ) õ (K.S…1 × PBW 562 and PBW 442 × INQ*3/ TUKURU// DBW 18 were evaluated for drought adoptive traits in restricted irrigated condition along with five check varieties HI 1500; HD 3043; HD 2987; DBW 43 and C 306 in four different agro-climatic conditions New Delhi, Pune, Powerkheda and Dindori. Genotypes G14, G10 and G34 are near to the ideal genotype for yield *per se* and genotypes G14, G45, G23 and G28 were near towards ideal genotype for thousand kernel weight. Molecular analysis of these 45 genotypes using 17 validated molecular marker present on 1B, 1D, 2D, 2A, 2B, 2D, 3A, 3B, 4A, 5A, 5B, 6A and 7B was done. Genotypes with minimum 4 to the maximum of 10 positive alleles out of 17 positive alleles segregating in the population were obtained. As expected genotype which contains more number of QTLs were out performed over checks.

Mean values of advanced lines over checks of wheat in multilocation testing

	DH	PHT	#QTLS	NDVI	CT	CHL	TGW	DM	Bio-mass	YLD
G1	76	98	7	0.77	22.71	52.8	41.45	117	7033	2727
G5	77	102	9	0.76	22.25	56.0	39.52	117	7072	2627
G10	72	98	8	0.76	22.32	59.2	37.23	118	5802	2865
G14	76	97	7	0.76	21.97	56.8	46.00	118	6933	2950
G19	79	96	10	0.80	21.53	55.4	38.70	119	5388	2543
G20	77	100	10	0.77	21.47	50.8	42.57	117	7155	2841
G21	72	102	8	0.78	22.95	56.2	39.97	117	7427	2877
G24	78	103	8	0.78	22.87	54.0	37.45	116	6641	2542
G27	73	102	7	0.77	21.96	52.3	44.77	116	7048	2513
G28	71	99	5	0.77	22.07	52.8	48.62	113	6335	2580
G30	75	88	9	0.77	22.73	51.0	39.00	118	5413	2639
G34	72	100	7	0.77	20.86	54.2	42.35	115	6522	2841
G35	71	98	6	0.78	22.51	52.5	41.72	117	7355	2475
G36	74	103	8	0.75	22.01	54.9	42.03	117	7173	2625
G37	75	93	7	0.74	22.81	59.7	49.00	116	6067	2577
G42	71	90	5	0.79	20.21	58.5	40.10	117	6628	2695
G43	78	101	6	0.77	22.62	54.4	40.23	118	7193	2495
DBW43	75	95		0.77	22.32	53.12	45.50	118	6293	2232
HI1500	74	109		0.76	22.32	53.33	41.20	115	6290	1785
HD3043	78	106		0.76	22.84	52.32	37.83	118	7035	2450
HD2987	66	89		0.69	22.47	52.63	43.43	117	6975	2533

Validation and introgression of validated markers into high-yielding Indian wheat cultivars

Elite Indian varieties HD2733 and GW322 from North-western plains zone and Central zone, and still covering a major share of breeder's seed indent, are targeted for improvement to abiotic stresses through marker assisted backcross breeding approach. Exotic wheat lines as Kauz, Excalibur, Rac875, Babax and indigenous lines viz. C306, HD2987, HI1500, WH730 and HD2888 were used as donor parents for transferring QTLs pertaining to drought and heat tolerance traits. Stress linked QTLs were validated in Indian set and international core set. Backcross populations had been advanced to BC_1/BC_2 F_2 after tracking QTLs for fore-ground selection and a range of 70-90 polymorphic microsatellite markers covering the entire genome (4-5 SSR markers per chromosome) being used for tracking the recurrent parent genome.

Intercrossed Progenie with high Yield Potential P159-2 /P 157-8

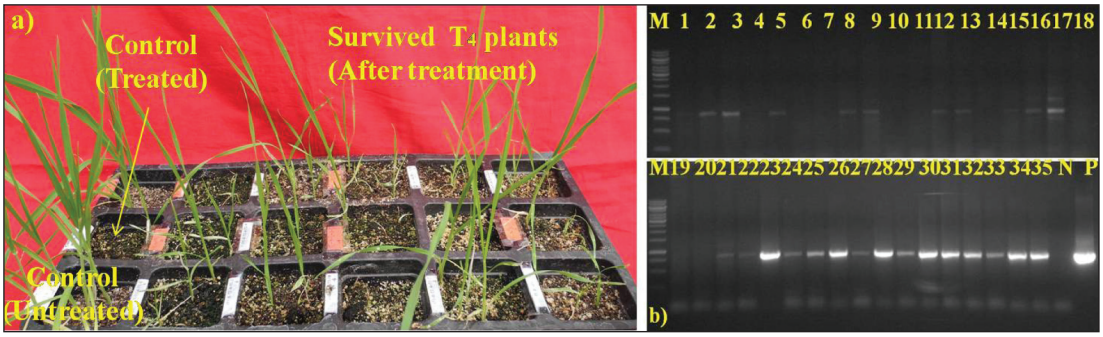
miR430, the master regulator for heat stress tolerance, identified from wheat

A novel miRNA was identified from HS-treated wheat *cv*. HD2985 using the de novo assembly and validated in contrasting wheat *cvs.* HD2985 and HD2329 through real-time PCR (qRT-PCR). Scatter plot analysis established the negative correlation between the expression of miR430 and their respective targets in different tissues of wheat under HS. The identified miR430 can be characterised and functionally validated in order to use it for the development of climate smart wheat crop.

Development of thermo-tolerant transgenic wheat (NRCPB)

Wheat transformation using *Inplanta* method and tissue culture based (Explant: Mature embryo) method of transformation with genes isolated from different systems: *Cpn60* (wheat cv WR544), *Dreb (E. coracana) and cspB (B. subtilis; codon modified)* is in progress. Genes for thermotolerance *{hsp17.9 (P. cineraria), CRT & P5CS (P. glaucum)* and *Asr & GolS1(Z. nummularia)}* are also being used for transformation of wheat. *Inplanta* derived thermo-tolerant transgenic plants (T_1 & T_2) transformed with *EPSPS + csp B*

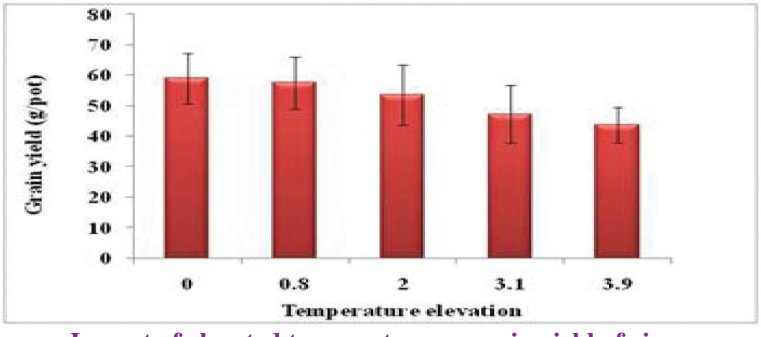
gene were screened by 0.5% commercial glyphosate treatment and confirmed by PCR. *Inplanta* transformation derived thermotolerant transgenic plants (T_1 & T_2) having *TapAPX* (peroxisomal ascorbate peroxidase) gene were screened by Hygromycin (50mg/l) treatment and survived plants were confirmed by PCR, southern hybridization. Different biochemical assays (APX assay, proline assay, chlorophyll content and RWC) after heat stress of 37°C for 6 hours confirmed the expression of transgene in transformed lines.



Screening of Inplanta T_4 *EPSPS* transgenics by Glyphosate treatment. b) PCR confirmation of survived T_4 plants.

Phenotyping for high temperature tolerance in rice (IARI)

Impact of elevated temperature on yield and nutrient uptake of rice was assessed using Temperature Gradient Tunnels (TGT) with the mean temperature elevation in the order of 0ºC<0.8ºC<2ºC<3.1ºC<3.9ºC. Grain yield of rice crop decreased by 25.8% with rise in temperature by 3.9ºC due to decrease in yield attributes and increased spikelet sterility, while biomass yield reduced by 22.8%. Application of 125% N prevented yield loss of rice by 5.4% as compared to 100% recommended N dose. Uptake of N, P, K, Fe and Zn significantly decreased with rise in temperature. The results suggest that application of additional dose of nitrogen over the current recommended dose could help in adaptation to yield loss due to climate change. Management of nitrogen is likely to play a crucial role in future climate change scenarios for enhancing yield and nutrient uptake in rice crop.



Impact of elevated temperature on grain yield of rice crop

Marker assisted improvement of drought tolerance in the rice cultivars Pusa 44 and Pusa Basmati 1 (IARI)

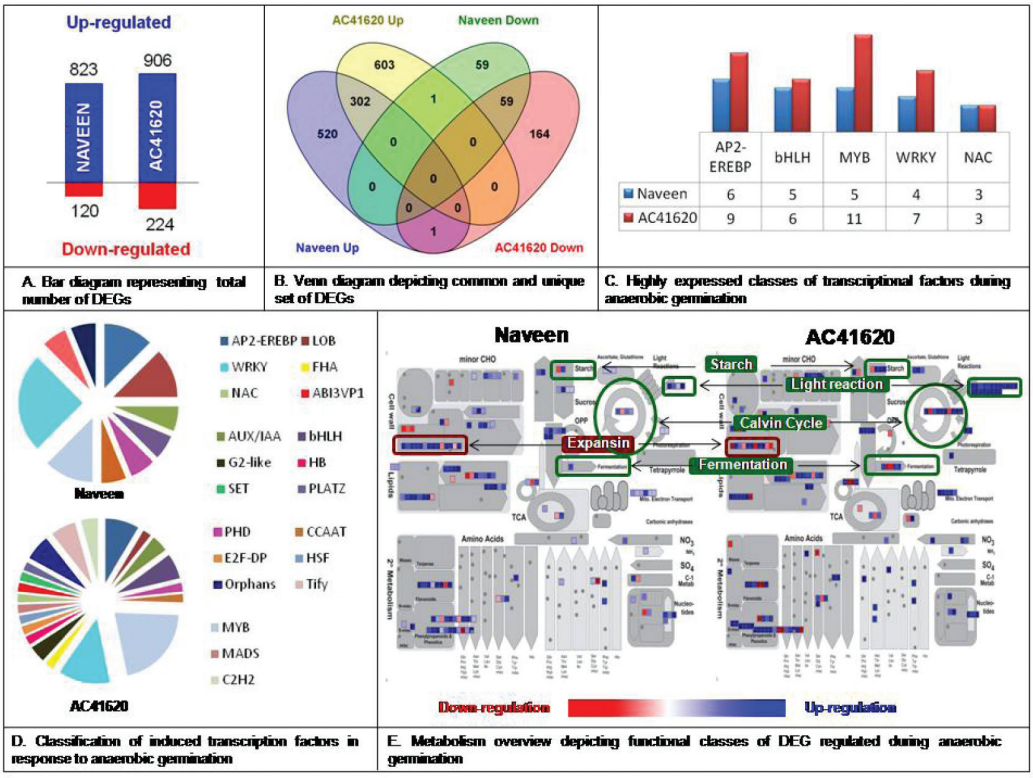
Based on the polymorphism screening using SSR markers linked to QTLs for drought tolerance between six donors and two recipient parents, a set of four QTLs for drought stress tolerance were identified for marker assisted introgression from five different donors into drought susceptible Basmati rice variety, Pusa Basmati 1 and non-Basmati variety, Pusa 44. Ten new crosses have been attempted with different donors using PB1 and Pusa 44 as recipient parents. Analysis of grain and cooking quality in the BC_1F_1 and BC_2F_1 progenies was carried out and desirable backcross progenies have been identified which have been advanced further.

Identification of key rice germplasm tolerant to different abiotic stresses (Sub-mergence, drought, salinity & multiple stress tolerance) (CRRI)

Experiments were conducted to assess the tolerance levels of genotypes to anaerobic germination, submergence, water-logging, vegetative stage drought stress, reproductive stage drought, salinity, stagnant flooding with salinity and salinity with drought.

Screening rice genotypes for anaerobic germination tolerance (CRRI)

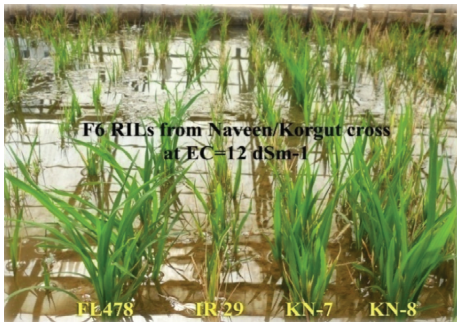
Unregulated flooding during germination in rice often leads to reduced seed viability, plant vigor and concomitant economic losses. Natural variation in genotypes of rice exists for tolerance to anaerobic germination. 510 rice germplasm lines were subjected to submergence with 10 cm water depth immediately after sowing. Among these, ten genotypes (IC282418, IC343457, IC337605, IC438550, IC337552, IC464837, IC467132, IC580215, IC369297 and EC545441) had shown tolerance to anaerobic conditions in terms of > 75 % germination with extended coleoptiles growth above the surface of water. RNA sequencing using the Illumina HiSeq2000 platform of two rice varieties, susceptible (Naveen) and tolerant (AC41620) to anaerobic germination at the global transcription level 48 h after anoxic stress during germination and subsequently aligning to rice indica reference genome led to identification of 943 and 1130 differentially expressed genes (DEGs) were identified in Naveen and AC41620 respectively. Pathway analysis using MAPMAN revealed that genes involved in light reaction, Calvin cycle, starch metabolism and fermentation were either over-represented or highly expressed in tolerant AC41620 whereas expansins were found to be highly expressed in Naveen. The identification of DEGs and transcription factors will serve as a useful genomic resource towards understanding of molecular mechanism of anaerobic germination in rice.



Transcriptome profile of anaerobic germination tolerant and susceptible rice cultivars

Evaluation of mapping population for salt tolerance in rice at seedling stage (CRRI)

Forty five among 175 lines belonging to a backcross population from IR64/Pokkali (AC41585) were found tolerant to moderately tolerant at seedling stage. From two hundred and ten F_6 RILs from Naveen/Korgut cross, only 7 lines have been detected with salt tolerance at seedling stage at 12 dSm^{-1}



A few tolerant lines as compared to tolerant (FL478) and susceptible (IR 29) checks in a mapping population derived from Naveen/Korgut under salinity stress (EC=12 dSm^{-1}) at seedling stage

QTL analysis for salt tolerance at flowering stage

Around 650 SSR markers have been tested for polymorphism and 60 markers situated in 9 chromosomes have been used to genotype IR64/Pokkali backcross population of 89 lines. Thirteen QTLs for four traits have been detected in chromosomes 2, 3, 4, 5, 6, 7 and 12. One QTL with additive effect that present in chromosome 4 in 16cM position in between RM 16801 and RM 17115 was common for stability index (trait under stress/

trait under normal condition) of number of panicles/plant, number of spikelets/panicle, harvest index and explained about 40-46% phenotypic variation of these traits. One important QTL has been found in chromosome 5 for stability index for number of grains/ panicle. One QTL with additive effect for stability index for grain yield/plant has been found in chromosome 7 in between RM180 and RM182. Two lines CR2851-1-1-S-7-2B-1 and CR2839-1-S-11-1-B2-B-46-2B derived from Gayatri/SR-26B and Swarna/ FL-496 respectively have been nominated to AICRP multi location trial under coastal saline area.

Drought tolerance and multiple abiotic stress tolerance in rice (CRRI)

Evaluation of rice germplasm for drought stress tolerance

Out of 66 accessions tested, 4 accessions JRS-21, AC-34280, AC-1781 and KD-2 had no symptom of leaf rolling. Amongst short duration germplasm lines, IC-337579, IC-337605 and IC-337596 (1.39 t ha^{-1}) recorded highest yield (>1.3 t ha^{-1}) with high biomass (>4.0 t ha^{-1}), HI (0.23 to 0.31) and high grain filing (50-70%); genotypes EC-545088, IC-311011 IC-426044 and IC-382660 had highest yield (>1.5 t ha^{-1}), with total biomass (>4.0 t ha^{-1}), HI 0.13 to 0.32 and grain filling (30-70%). In terms of root traits, out of 80 genotypes tested, Chhota jangia, AC-42997 and AC-43038 were found superior consistently in both the years 2013 and 2014. Genotypes Kalabora, AC-492994, Brahmaninakhi and Bor janghia found to have tolerance to reproductive stage drought which was further supported by photosynthesis, leaf water relations and stomatal conductance.

Rice cultivars tolerant to water logging and salinity

Assessment of 10 cultivars for tolerance to salinity and water logging by imposing partial submergence (35-40 cm water depth) with saline (8 dS m^{-1}) and non-saline water resulted in identification of rice cultivars AC 39416A and SR26B as highly tolerant for partial submergence along with salinity.

Identification of drought tolerant rice for NEH Ecosystem (ICAR-NEH)

Phenotyping of the mapping population (CT 9993-5-10-1-M/2*SAMBHA MAHSURI) developed for drought QTL identification has yielded selections which are high yield, early duration and fine grain quality even under severe drought stress. Presently the mapping population has 311 RILs. Six mapping populations for QTL studies on drought tolerance in rice viz., RCPL 1-128 x Naveen, Bhalum 3 x Naveen, Fulbadam x Swarna, Kataktara x Naveen, Fulbadam x Naveen and Kataktara x Swarna were advanced to F_4.

Genotyping of 45 land races collected from *jhum* areas in Tripura with 200 SSR markers indicated polymorphism for 52 markers.

Developing trait based breeding populations for heat tolerance and NUE in Rice (IIRR)

One thousand and eighty six rice breeding lines (F_1 to F_7 generations) were evaluated in field conditions during Kharif and rabi seasons. In addition, 310 selected rice lines (advanced breeding lines, hybrids and selections from mapping populations) were also evaluated in heat tunnel. Two mapping populations Vandana x Nagina 22 (F_3 populations) and 166-30 x Nagina 22 (F_2 populations) were phenotyped for 25 morpho-physiological traits. Polymorphic survey with 1100 SSR markers covering all 12 chromosomes resulted in identification of 100 polymorphic markers with the 4 parents.

Five heat tolerant lines previously reported have been evaluated at 9 locations under AICRIP and except GQ25 lines other four lines confirmed expression of genes for some of the traits associated with heat tolerance and found to be stable.

Introgression of QTL for heat tolerance (qHTSF4.1) into parental lines of hybrid rice (IIRR)

Nagina-22 was identified with heat tolerant QTL qHTSF 4.1 which is effective with spikelet fertility under high temperature conditions. Introgression of this QTL by Marker Assisted Back Cross (MABC) method in KMR3 x Nagina cross during previous year yielded 32 positive lines which were confirmed using RM11943 marker and forwarded to BC_2 F_2.

Identifying QTLs by screening of existing mapping populations: 250 Madhukar x Swarna F_8 RILs for 25 traits associated with heat tolerance and yield. Linkage maps were developed and four common QTLs explained 55-73% phenotypic variance. Some of the promising HT lines identified from different mapping/background selections from Swarna x *O.nivara* (ILs) are: 24 (K), 65 (s), 175-2 (K) 230 (s). Similarly from KMR3 x *O.rufipogan* ILs are: 16-3, 377-24., S-458 and NH 219 (N22 mutant).

Trait		DS 2012			DS 2013		
	Chro	Flanking Markers	LOD	PV	Flanking Markers	LOD	PV
No. of Unfilled grains	1	RM428-RM1	3	55	RM428-RM1	15.2	62
Spikelet fertility	1	RM428-RM1	6.9	58	RM428-RM1	9.9	54
Days to 50% Flowering	3	RM16-RM426	16	72	RM16-RM426	11.5	73
Days to 50% Flowering	6	RM314-RM19697	16.7	72	RM314-RM19697	8.3	71

Genome wide identification of heat stress responsive miRNAs; In N22 and Vandana using illumina platform led to identification of two important genes namely cell wall integrating (CWIP) protein and OsFd iron sulphur gene particularly associated with heat stress recovery phenomenon.

Development of heat tolerant rice hybrids (IIRR)

IRHTN-2012 lines were used in hybridization programme with four different CMS lines (APMS6A, IR58025A, IR79156A and IR68897A) to check the combining ability, fertility restoration, maintainer's ability and heterosis. Three restorer lines were identified based on combing ability and heterosis with different CMS lines and presence of restoring fertility gene *Rf4*. Three hybrids which had shown 98 percentage of genetic purity in a Grow out test (GOT) are IR58025A X NH-12-141R (HHZ12-SAL8-Y1-Y2); APMS6A X NH-12-124R (HHZ12-SAL2-Y3-Y2); APMS6A X NH-12-144R (HHZ5-DT20-DT2-DT1). These hybrids will further be evaluated in multi location testing.

Transcriptome profile of anaerobic germination tolerant and susceptible rice cultivars

Nitrogen Use Efficiency: 258 entries were evaluated (treatments N0, N50 and N100), four F2 populations, and RIL (BPT 5204 X PTB1) for the physiological performance of the NUE and yield in field conditions. About 25-30 Kg N reduction is recorded in N0 plot during 2014-2015. Polymorphic survey was conducted with 250 SSR markers and 39 markers were found to be polymorphic between the parents and 7 markers were found to be linked to grain yield under low nitrogen level. Five candidate genes were identified and expression analysis was carried and confirmed in the previously identified donor lines with heat tolerance and NUE.

Development of segregating materials, identification of genotypes and genomic regions: Association mapping of 472 genotypes with 50 rice microsatellite markers covering 12 chromosomes for the 90 parameters indicated that out of tested markers, 30 were associated with more than 10 traits with validation in Rasi/Vibhava population. Differential expression in RP Bio 4919-377-13, Varadhan, Krishnahamsa and RP Bio 226 indicted that alanine ammonia transferase gene might possibly be associated with NUE. Similarly expression analysis of nitrate reductase, PAL and ammonium transporter genes in 10 high NUE genotypes also revealed their role in nitrogen use efficiency.

First set of 6 each of promising and parental DNA fingerprinted rice lines with superior NUE are being subjected for multi-location testing during kharif 2015.

Phenotyping of maize for drought and heat tolerance (CRIDA)

In *Kharif* 2014 and *Rabi* 2014-15, field evaluation for water deficit stress tolerance in maize utilizing 54 & 63 selected genotypes respectively revealed significant association of drought tolerance traits with yield.

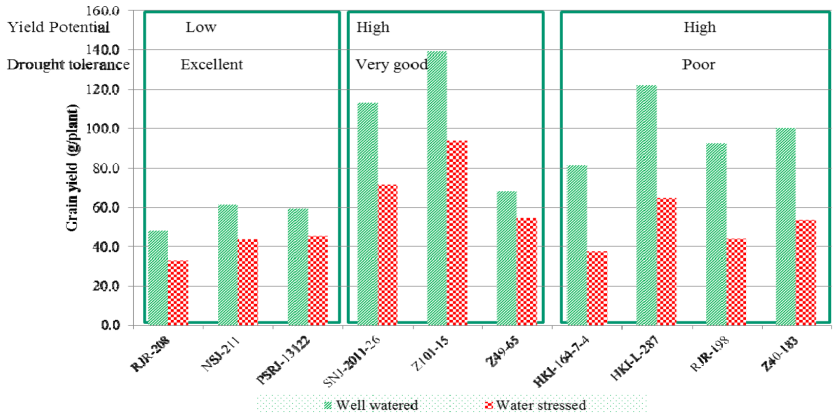
The materials evaluated showed high variation for various morpho-physiological traits. ELWRC of the maize genotypes revealed that NSJ211 and Z59-17 retained ~ 82 % of moisture while HKI-164-7-4, 18301 and HKI-766(0) retained ~70% of moisture. Among the genotypes, Z101-15, Z40-19, NSJ245, Z32-87, NSJ366, 18224,18229,18261,18171 and 18242 showed better performance in the various adaptive traits. Similarly, PSRJ 13086, Z32-87 and RJR 208 maintained higher relative water content (RWC) while the genotype Z40-183 and Z59-17 showed lower RWC among the genotypes tested. Genotypes 32977 and 32934 maintained higher RWC while the genotypes 32451 and 31737 showed lower RWC.

Some of the genotypes, identified for drought tolerance/susceptibility for specific morpho-physiological traits (viz. RWC, transpiration efficiency, stomatal conductance) were used in crossing for developing mapping population for these traits in maize.

Of the 20 F_1 crosses evaluated, three trait specific crosses i.e., Z59-17 X Z40-183, RJR 208 X Z32-87 and RJR 132 X SNJ2011-26 have been selected and forwarded to F_2 generation for further evaluation.

Three crosses (HK1-766 (O) / HK1-161, HK1-766(O)/Z93-194 and HK1-766 (O) / Z40-19) were advanced to F_3 and one cross (SNJ2011-17 / PSRJ 13154) to F_4 generation during kharif 2014.

Genetic diversity analysis based on 80 polymorphic SSR markers revealed that the parents involved in crosses belonged to diverse groups.



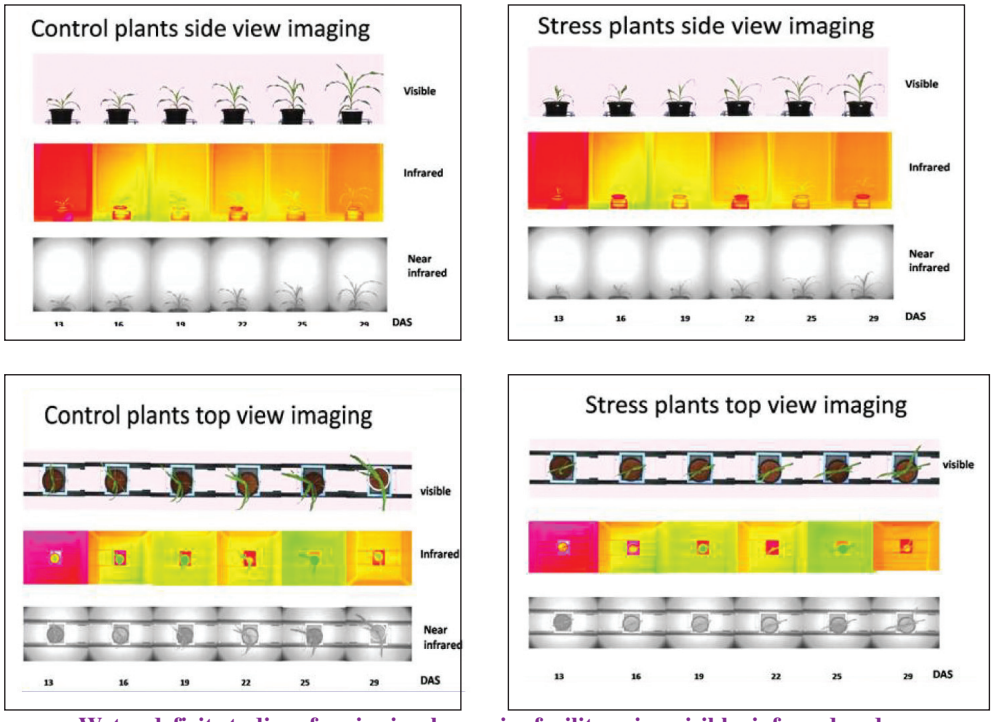
Grain yield of tolerant and susceptible genotypes under well watered and water stressed condition

A comprehensive analysis of the stress tolerance studies under well watered and water stressed conditions across three seasons of 27 genotypes revealed crucial interactions as well as association amongst physiological traits such as water relations and stomatal conductance, with yield and yield components. Drought susceptibility index developed based on yield as well as morpho-physiological traits across the environments and seasons were useful in identifying genotypes with high yield and very good drought tolerance.

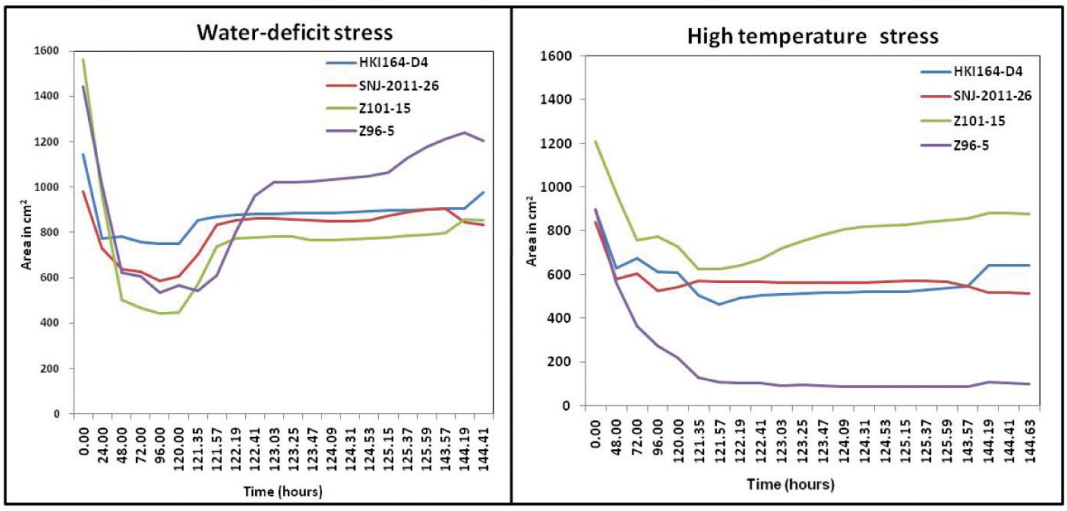
Significant association of a few SSR markers with above traits was evident indicating the interaction of several genes involved in stress tolerance thus maintaining the primary as well as cumulative metabolic functioning to cope with water-deficit stress.

Whole Genome Micro-array in water stressed and control plants of maize was also initiated to determine which genes regulate responses to water stress and also determine if phylogenetically similar genes have similar responses to water stress. Data on the expression of 4500 genes and transcription factors in the maize genome was obtained and their expression pattern indicated that ABA metabolism related, signaling and osmoticum related genes were highly over expressed. This suggests that mechanism of drought action is mainly regulated by these pathways.

To optimize high throughput screening technique for identification of drought & heat tolerant genotypes in maize



Water deficit studies of maize in phenomics facility using visible, infrared and near infrared imaging techniques



Transcriptome profile of anaerobic germination tolerant and susceptible rice cultivars

In an effort to optimize the stress imposition, image acquisition and analysis in response to water deficit and high temperature stresses and recovery patterns in maize, systematic assessment was accomplished using the outputs from visible images from sides and top generated by the Scanalyzers of phenomics facility.

Water deficit stress was imposed by with-holding water at 43 DAS for 3 days in 4 genotypes of maize (HKI-164 D4, SNJ-2011-26, Z-96-5 and Z101-15) after which stress was relieved. High temperature stress was imposed separately on the same set of genotypes for 6 days at 38°C and recovered thereafter at 30°C. Images were acquired at 24hr interval during stress and at 22 min. interval for one day during recovery in both the stresses.

The quick recovery trends observed within an interval of less than half-an-hour after relieving the stress by genotype Z96-5 under water deficit and Z101-15 under high temperature stress demonstrate the potential of using high throughput phenomics for precise screening of germplasm against climatic stresses.

Identification of temperature tolerant maize for NEH Ecosystem (ICAR-NEH)

The increase in H_2O_2 content in response to heat stress was relatively lower in RCMGP63 and RCMGP105 in a set of 6 maize genotypes evaluated for high temperature stress tolerance. High phenolic content in these two genotypes at 10 and 20 days under elevated temperature of 37°C indicated a stronger defense system in these genotypes further corroborating the previously reported observations on stress tolerance of these genotypes.

***Multi-locational testing of advanced terminal heat tolerant wheat lines*:** Forty five Advanced lines derived from cross between **DBW 43 × HI 1500, VL755/UP2338/ /BAU/KAUZ) õ (K.S…1 × PBW 562 and PBW 442 × INQ*3/ TUKURU//DBW 18** were evaluated in multi-location (4 locations) trials **(IARI)**

Nomination of rice entries to AICRIP trial for salinity tolerance: Two lines **CR2851-1-1-S-7-2B-1 and CR2839-1-S-11-1-B2-B-46-2B** have been nominated for AICRIP multi-location trial under coastal saline area. Yield of these lines was found 4000-4130 kg/ha under saline (EC= 4-7 dSm-1) condition. **(CRRI)**

Three hybrids, IR58025A X NH-12-141R (HHZ12-SAL8-Y1-Y2); APMS6A X NH-12-124R (HHZ12-SAL2-Y3-Y2); APMS6A X NH-12-144R (HHZ5-DT20-DT2-DT1) with 98% genetic purity in a Grow out test will be evaluated in multi location testing. **(IIRR)**

Heat and or NUE trait based 5 donor lines of rice were subjected for multi location testing (8-9 locations) under AICRIP out of which four lines viz., **Somaly-2-023-3-5-1-2-1, IR 55178, SG 26-120 and IR 82310-B-B-67-2** confirmed the stability and performed well under late planting situation. **(IIRR)**

First set of 6 each of promising and parental DNA fingerprinted rice lines with superior NUE, viz., **NBTPL1 to NBTPL6 and NBTPP1 to NBTPP6** will enter multi-location testing in 2015. **(IIRR)**

Two extra early greengram genotypes **IPM 409-4 and IPM 205-7** identified to be suitable for summer cultivation is in the process of release. **(IIPR)**

Improving productivity and resilience of kharif pulses (Pigeonpea, Mungbean, and Urdbean) under rainfed agro ecosystem (IIPR)

Ten drought tolerant pigeonpea varieties/lines Bennur local, JSA 59, JKM-189, BSMR-736, VKS-11-24-2, JKM-7, RVK-275, Bahar, IPAC-79, ICP-12654 with consistent higher productivity over the years were identified based on multi-locational trails conducted at Kanpur, Ludhiana, Badnapur and Gulbarga. Physiological assessment of the above genotypes under controlled conditions in rain-out shelter indicated high osmotic adjustment ranging from 0.85-3 MPa, which perhaps contributes to improved drought tolerance in these.

Wild accession of pigeonpea *C. scaraboiedes* has been characterized as drought and heat tolerant in view of its high osmotic adjustment, ability of pollen germination and setting pots at high temperature of even 47°C. The crossing material of this wild accession have been advanced further at F_4 stage and promising lines in terms of high yield as well as traits from wild relative have been identified.

Wild Pigeonpea *Cajanas scarabaeoides* sets pod at 47°C

Fertile germinating pollen at 47°C

High initial chlorophyll content and *aerenchymatous* cells were found to be important factors in the physiological mechanism of tolerance to water logging in pigeonpea which was characterized in genotypes IPAC 79 and MAL 9.

Evaluation of Greengram

Heat tolerant greengram lines/varieties were identified based upon Thermal induction response (TIR). The lines IC 296679, Ganga 8, BDYR-1, EC 520014, PS 16, OMG 1030, V-3518, UPM 98-1 survived heat shock at 52°C. TIR coupled with fluorescence imaging proved to be a highly effective screening technique for heat tolerance. A number of crosses were made using the two identified photo-thermo-insensitive *Vigna* lines

V. umbellata, IC251442 and *V. glabrescense*, IC251372. Two extra early greengram genotypes IPM 409-4 and IPM 205-7 identified to be suitable for summer cultivation are in the process of release.

Extra Early green gram genotypes

Evaluation of blackgram

Heat and drought tolerant donor lines in blackgram were identified such as IPU 99-43, IC 106068 (tolerant) and Shekhar and STY2289 (moderately tolerant) which could be further used in genetic enhancement of heat & drought tolerance in this crop.

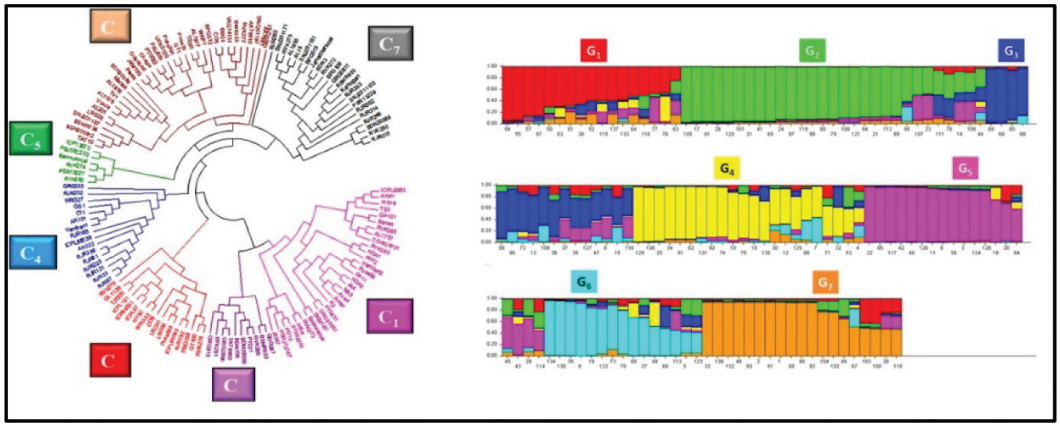
PGRU 95016, a photo-thermo-insensitive & thermo-tolerant genotype in blackgram which was identified in the previous year to flower at both 10 and 16 h photoperiod was further characterized based on thermal degree days. The genotype flowered at both 25/15°C and 36/20°C max/min and also had ability of pollen germination at 43°C.

Field screening of pigeonpea germplasm for drought and heat stress (CRIDA)

Field evaluation of thirty genotypes of pigeonpea representing early (< 55 days to 50% flowering), medium (<110 days to 50% flowering) and late maturing (>110 days to 50% flowering) led to identification of AL 1702, BDN 708 & RVK 274 as tolerant with higher photosynthesis rate, Stomatal conductance, transpiration rate, SCMR along with higher yield under rainfed conditions.

Characterization of 138 released cultivars along with some advanced lines of pigeonpea acclimatized to diverse agro climatic conditions in the country; using 34 SSR markers associated with putative drought related function classified the cultivars into different diversity groups which could be useful in development of mapping population for identifying QTLs for drought related traits.

Fifteen of the tested markers were polymorphic and a total of 52 alleles were obtained with an average of ~ 1.6 alleles per primer set. The germplasm tested was grouped in 7 sub-populations. The Nei genetic distance, which represents diversity among the genotypes, was highest between PAU-881 and LRG-41; PT-00-022 and LRG-41.



Model based clustering and structure analysis of 138 pigeonpea genotypes using SSR marker data

Evaluation of mungbean germplasm for drought tolerance (NIASM)

Evaluation of mungbean germplasm obtained from NARS institutes like NBPGR, PAU, and IIPR along with local checks Vaibhav & BPMR-145 for genetic variation in canopy temperature and chlorophyll fluorescence, physiological traits contributing to drought tolerance revealed maximum fluorescence in BM-2003-2 while genotype VC-3960-BB was able to maintain high fluorescence even at high canopy temperatures. A very low

drought susceptibility index was recorded in genotype IC-16033 and ML-2082 followed closely by Vaibhav, reflecting their yield stability under deficit moisture conditions.

Phenotyping of chickpea genotypes for low temperature tolerance (IARI)

Using staggered sowing approach wherein the late sown crop experienced low temperature during the vegetative stage (~13.3°C average daily mean temperature) compared with early sown crop (~17.1°C average daily mean temperature), it was found that marked reduction in total biomass accumulation and seed yield was associated with low temperature during vegetative stage. Chickpea genotypes BG-1088, JG-11, RSG-963, PUSA-2024 were found to be tolerant compared to other tested genotypes.

Prospecting of Genes for Thermo-tolerance from Microbial and Plant Resources (NRCPB)

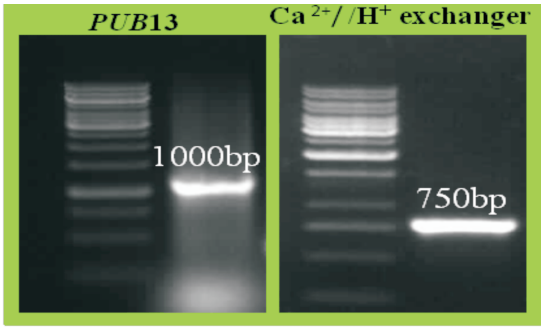
Transcript Protein Phosphatase2c (*EcPP2C*) from finger millet was isolated and cloned in binary vector (PBI121) for transformation in wheat. Full length CDS of heat responsive *GPx* (Glutathione peroxidase) from wheat cv. Raj3765 was isolated, cloned in pET expression vector and binary vector pCAMBIA1300-PUbi. Cloning of genes for thermotolerance from microbes {otsBA & OtsA: Trehalose phosphate phosphatase & trehalose-6-phosphate synthase; Codon modified *MPGS* gene: *mannosyl phosphor glycerate synthase*, *TreS:* trehalose synthethase} is in progress.

Prospecting of genes for multiple stress tolerance (CRIDA)

Identification of novel genes through Suppression Subtractive Hybridization (SSH)

ESTs obtained from high temperature and salt (NaCl) stress-induced cDNA libraries in pearlmillet were deposited in the EST database of NCBI website with the library ID LIBEST_028446 (JZ705005-JZ705123) and LIBEST_028447 (JZ705124-JZ705239) respectively. Full- length sequence of CDPK has been deposited in the GenBank with the Accession number KJ923435.

Two genes commonly expressed under all the three stress-induced (water-deficit, salt and high temperature) cDNA libraries constructed in pearl millet, PUB13 and Ca^{2+}/H^{+} exchanger were targeted for isolation of full length gene sequences. Plant U box E3 ubiquitin ligase (*PUB*13) plays an important role in defense and flowering time control. The Ca^{2+}/H^{+} antiporters located in tonoplasts, chloroplast, thylakoid membranes and in the inner membrane of



PCR amplification of full length gene sequences of *Ca^{2+}/H^{+}* exchanger and *PUB13* .

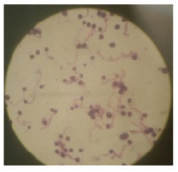
mitochondria, play a role in Ca^{2+} signal transduction and ion homeostasis. PCR amplification of cDNA isolated from stressed seedlings of pearl millet using PUB13 and Ca^{2+}/H^{+} exchanger gene specific primers resulted in the amplification of 1000bp and 750bp products respectively. These genes will be further cloned and characterized.

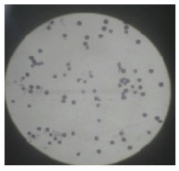
Enhancing tolerance of horticultural crops to climatic stresses (IIHR)

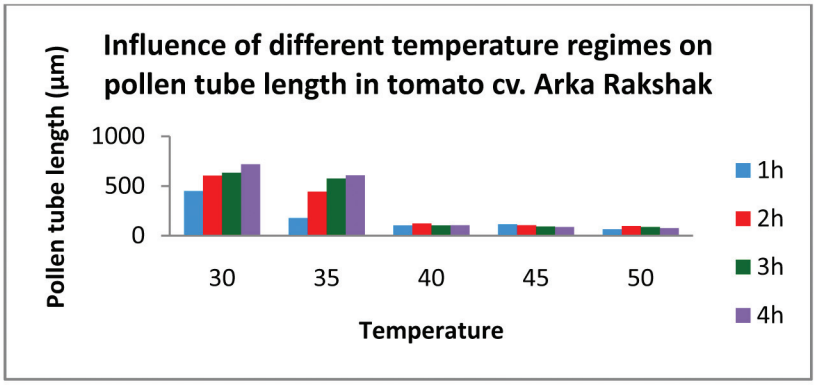
Evaluation for heat tolerance in Tomato

Two firm fruited tomato lines (IIHR-2834 & IIHR-2835) with good general combining ability (GCA) were crossed with heat tolerant (HT) lines (IIHR 2852 & IIHR 2853) in order to transfer heat tolerance. Four back cross (BC1F2) populations *viz;* (IIHR 2835 x IIHR 2853) x IIHR 2835, (IIHR 2835 x IIHR 2852) x IIHR 2835, (IIHR 2834 x IIHR 2853) x IIHR 2834 and (IIHR 2834 x IIHR 2852) x IIHR 2834 were raised and seeds were collected from a total 84 BC1F2 and planted during summer 2015 (BC1F3) for further advancement. A total of 251 F_3 plants of the cross involving large fruited HT line (CLN 3125A) and drought tolerant (RF_4A) line were raised and screened for heat tolerance.

PCR amplification of full length gene sequences of *Ca^{2+}/H^{+}* exchanger and *PUB13* .







Temperature Induction Response (TIR) studies by gradual exposure of seedlings at 4 leaf stage to induction temperatures 33-42°C for four hours and subsequently to high temperature of 50°C for three hours identified 4-3-3 and H329 as heat tolerant based on recovery in photosynthesis.

The pollen germination studies in segregating lines of cross between 3125A and RF4A indicated that twelve lines exhibited more than 75% germination at 40°C.

Breeding for drought tolerance in tomato

A total of 251 F_3 plants of the cross involving large fruited HT line (CLN 3125A) and drought tolerant (RF_4A) line of tomato were raised and screened for stress tolerance. Seeds were collected from 219 F_4 plants for further advancement during Rabi 2015.

There was considerable variation in pollen germination under water stress in tomato cultivars grown under limited water stress. Maximum pollen germination (44.7%) was observed in IIHR 15SB followed by Arka Rakshak, IIHR-2890 53752 and IIHR-2338 (17.0 – 21.5%) at 35 ^{0}C

Inoculation of osmo-protectant bacteria improved significantly growth and yield under water stress. At 50% and 25% water holding capacities, growth parameters and yield of tomato plants inoculated with *Citricoccus zhacaiensis* strain B-4 were significantly higher than control indicating the ability of this action-bacterium in enhancing yields under moisture stress.

Response of grafted tomato plants to water deficit stress

Root stock grafting is considered simple and effective besides being cost-competitive strategy for alleviating the plant responses to abiotic stress in vegetable crops. Tomato is sensitive to water deficit stress. Tomato (hybrid, Arka Rakshak, AR) was grafted on two brinjal rootstocks and defined as: ungrafted-Arka Rakshak (UG-AR), Arka Rakshak/ Arka Neelkhanth (AR/AN) and Arka Rakshak/ 2BMG-1 (AR/BMG-1). Water stress was imposed at flowering stage for a period of 12 days and released thereafter. The soil moisture was 26.0, 15.0 % and 7.0% in irrigated, 50% and 100% stress levels respectively on day-12. The reduction in photosynthetic rate was relatively less in grafted plants as compared to ungrafted plants while root length and volume as well as pollen germination were higher in grafted plants across the stress levels as compared to ungrafted plants. The response was better in AR/2BMG-1.

Screening of tomato genotypes tolerant to climatic stresses (IIVR)

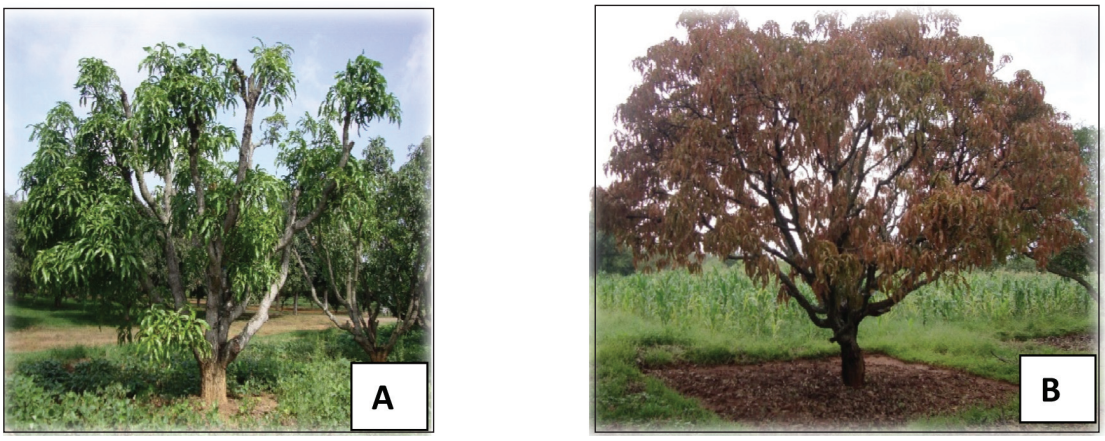
Temperature gradient tunnel (TGT) studies with eleven genotypes of tomato (nine tolerant - CLN-1621, CLN-2026, EC-620438, EC-620421, 15 SB, EC-620386, EC-538441, TLH-27 and C-26-1 and two susceptible CO-3 and Hisar Arun) revealed that CLN-1621 and EC-538441 showed higher pollen viability at all 6 temperature gradient with the viability of 87% at highest temperature of up to +9^{0}C from the ambient temperature. CLN-1621 also exhibited higher fruit setting percentage (72.36%) and high total fruit weight (685 g/plant) at highest temperature regimes.

Flowering phenology in mango (IIHR)

Relationship between temperature and maximum anthesis, anther dehiscence and stigma receptivity in mango

Studies on relationship between temperature and maximum anthesis, anther dehiscence and stigma receptivity in mango revealed that maximum anther dehiscence within a day was observed when the temperature reached around 29.0°C. Early dehiscence is better for pollination and fertilization since pollinator activity was more during early hrs of morning.

Research initiated in the year 2012 to understand the staggered behaviour of flowering were continued through the current year. Since staggered flowering in Alphonso mango is apparently associated with inadequate carbohydrate reserves in the trees necessary for allocation to flowering activity, rejuvenation of the trees through pruning and defoliation was taken up on a large scale. Complete defoliation of Alphonso mango trees has resulted in highly synchronized vegetative shoot formation with the primordia getting activated within 5 to 10 days after defoliation irrespective of the month as compared to selective pruning of tertiary branches. Active primordia were lost by pruning the tertiary branches resulting in delayed activation of the cambium to produce new primordia and thereby shoots and flowering. The canopy architecture was observed to be retained by complete defoliation while pruning of tertiary branches resulted in altered canopy architecture as a result of emergence of multiple shoots from the pruning point



Rejuvenation of Alphonso trees through top pruning (A) and complete defoliation (B) to induce synchronized vegetative growth

Quantification of biomass using Phenomics Platform (IIHR)

The standardization for quantification of fresh and dry mass production of tomato (Arka Rakshak) was carried out using the out puts from visible images from two sides and top generated by the scanalyzers of Phenomics platform. The relationship between digital

biomass and actual biomass of tomato plants showed high correlation with R^2 of 0.96 for fresh mass and 0.94 for dry mass.

Visible images of tomato plants generated by the software for quantification of digital biomass

Assessment of Impact of Climate Change on Productivity and Quality of Sugarcane (IISR)

Analysis of relationships between weather parameters and sugarcane yield and juice quality using AICRP data from 2008-2013 revealed that irrespective of the ripening behaviour of the varieties, sucrose % juice was lesser in the years with relatively higher rainfall and relatively lower maximum and minimum temperatures during October months. Sugar recovery was influenced by the range of temperatures during ripening phase (November to March) as well as grand growth phase (during July). With increase in range of temperature during November to March sugar recovery increased while with the increasing range of temperature during July, the sugar recovery decreased.

Impact of elevated CO_2 and temperature on cotton productivity (CICR)

Under elevated CO_2, both pruned plants and normal seeded crop gave significantly higher yields as compared with ambient condition. In general, hybrids produced more bolls under elevated CO_2, than cultivars. Morphological and productivity attributes were favorable at 1°C above ambient under elevated CO_2 (650 ppm). Further increase in temperature adversely affected the plant growth and development.

4.4 Pest and Disease dynamics and Pollinators

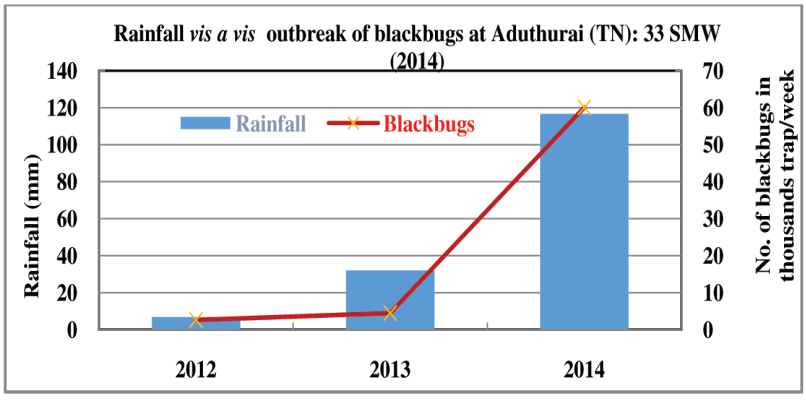
Pest dynamics in relation to climate variables across different regions (NCIPM, CRIDA, DRR, IIHR, ICAR-RCER)

One of the key impacts in climate is on dynamics of pests and diseases and emergence of new races of pests. In order to assess the changing pest and disease dynamics, a country level pest monitoring system in relation to concurrent weather parameters was taken up under NICRA involving 32 locations covering 5 crops. The seasonal dynamics of pests was recorded on a real time basis using a software. Twenty five real time pest dynamic (RTPD) centers from 11 states, across 11 agro-climatic zones covering 12 agro ecological regions were continued for the fourth year for the crops of rice, pigeonpea, groundnut & tomato) during *Kharif* 2014 and across 17 locations for *Rabi* 2014-15. A comprehensive standalone information system on 'Diagnosis and Sampling for Pest Surveillance (DSPS) for Rice, Pigeonpea, Groundnut and Tomato have been developed as a window based application using asp.net with C#. Comparative analysis of pest scenario *vis a vis* weather variables from climatic variability perspective was made considering the data base over three *Kharif* (2011-2013) and *Rabi* (011-12 – 2013-14) seasons for seven, six, five and seven RTPD locations in respect of 34, 23, 27 and 30 parameters (including insects, diseases, beneficial, light and pheromone trap catches) corresponding to rice, pigeonpea, groundnut and tomato crops.

Pest scenario *vis a vis* climatic variability

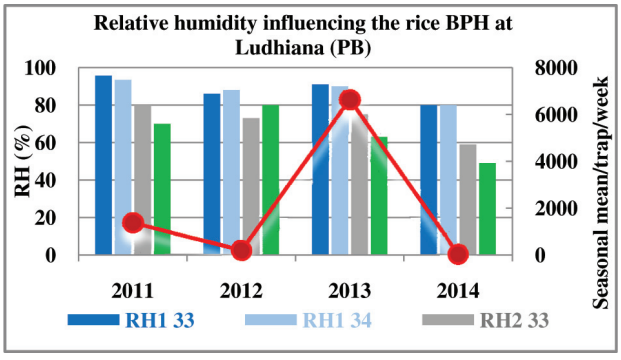
Rice

While outbreak of rice black bug, *Scoutinophara lurida* Burmeister was seen at Aduthurai (Tamil Nadu) due to greater and unusual rains during 33 standard meteorological week (SMW), Ludhiana (Punjab) witnessed highly reduced rice brown plant hopper, *Nilaparvata lugens* due to the absence of rainfall and the associated reduced humidity levels during the 33 and 34 SMWs. Although direct effects of weather were minimal, the delayed monsoon and canal water release and extended *Kharif* season with greater than 50mm rainfall as against 7.9 mm normal in three rainy days during 27 SMW triggered the brood emergence.



Use of synthetic pyrethroids coupled with high relative humidity (>85%) favoured the population buildup of brown planthopper, *Nilaparvata lugens* during the first fortnight of December across experimental and farmer fields of Thanjavur (TN). In Mandya (KA), the heavy pre-monsoon (243mm in May) and prolonged rainfall during June(53mm), July(72mm), August(114mm), September(141mm) and October(237mm) coinciding with the peak activity of rice pests led to reduced incidence of insect pests.

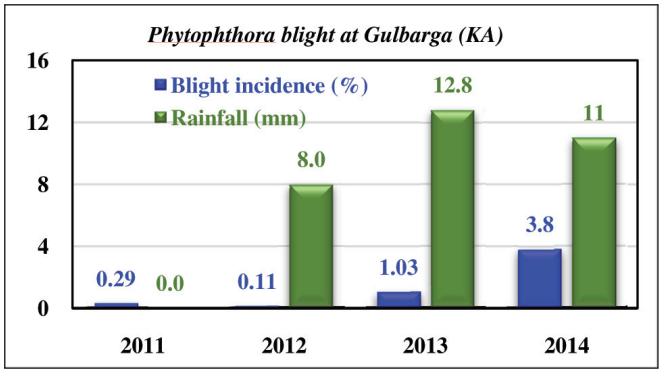
Decreasing incidence of rice stem borer and increasing case worm and leaf folder, later due to the late start of rains and the associated delayed transplanting at Karjat (MH). Unseasonal rains and cloudy weather at the time of *Rabi* rice harvest had the incidence of rice army worm throughout Raigad district.



Grain discoloration and unfilled grains of rice were observed in almost all parts of Chhattisgarh after cyclonic rains (Hudhud) occurred during 11-13 October 2014.Notable feature of *Kharif* 2014 has been the highly reduced rice BPH, *N. lugens* at Ludhiana (PB), and a holistic analysis indicated the absence of rainfall and the associated reduced humidity (RH) levels during the 33 and 34 SMWs as the major reason. Greater than 80 and 60 % morning and evening RH, respectively were inferred as the critical requirements for the development of BPH.

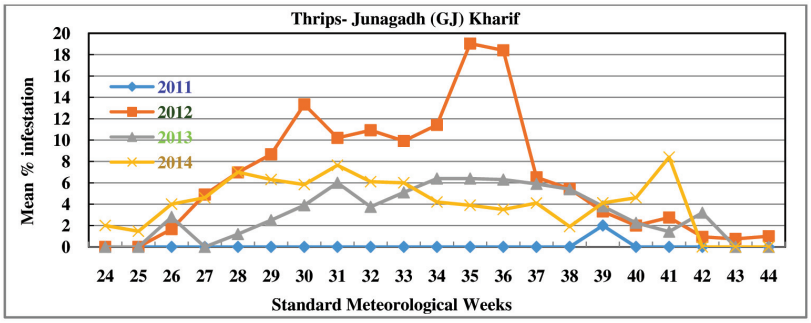
Pigeonpea

Heavy incidence of jassids (*Empoasca kerri*Purthi) during 2014 as against trace population in the past years was observed at Gulbarga (Karnataka) following the higher minimum temperature of 2-5°C above normal throughout the pre and post monsoon periods (mid-March – September) followed by torrential rains (195 mm in 35 SMW) coupled with dry spells and intermittent rains (>10mm). Pigeonpea *Phytophthora* blight is on the rise at Gulbarga in response to the increased rainfall over normal during the late crop growth stage. *Helicoverpa armigera* Hubner, *Grapholita critica* (Mego),*Adisura atkinsoni*(Moore)and *Exelastis atomosa*(Walshingham) were at their lowest during 2014 at S.K. Nagar (Gujarat) when the rainfall amount during the season (June - December) had been lower over previous three seasons.



In general and the pod bug, *Clavigralla gibbosa* was abundant during all the seasons, in particular. Foliar diseases *viz.*, *Alternaria* and *Cercospora* were lower at the hot arid location of Ananthapur (AP) over the hot semi-arid locations *viz.*, Warangal (Telangana) and Gulbarga (KA) with the former location showing increased maximum as well as minimum temperatures (1.5 - 3°C) over the normals through the years of 2011 – 2014 during pre and post monsoon periods of *Kharif*.

Groundnut



Higher temperature during pre-monsoon period coupled with delayed rains and late sowing of Groundnut at Dharwad (KA) followed by continuous rains till October during *Kharif* 2014 saw moderate to high (40-50% leaf defoliation) damage due to *Spodoptera litura* Fabricius and late leaf spot (Grade 5) with leaf miner at its low. Early and late season dry spells and comparatively high rainfall events amidst crop season during 2014 at Jalgaon (Maharashtra) had the increasing population levels of jassids *E. kerri*, thrips *Scirtothrips dorsalis* and leaf miner *Aproaerema modicella* (Deventer). The rare occurrence of thrips damage at maturity period of groundnut at Junagadh (Gujarat) in 2014 was due to the prevalence of high temperature in day time and absence of rains. The low amount of rainfall during the *Kharif 2014* at Kadiri (AP) witnessed the dominance of thrips infestation (28-52%) followed by jassids (20-48 %). Among the diseases, maximum severity of dry root rot (22%) were recorded at harvest stage where frequent dry spells with lesser intermittent rains occurred up to end of the season.

Tomato

South American tomato leaf miner, *Tuta absoluta*(Meyrick) was documented as a new invasive pest from India during *Rabi* 2014 at Bengaluru (Karnataka) with its severity continuing in *Summer* season also. Heavy rains of August (149 mm in 35 SMW as against normal of 21 mm) in 2014 led to *Phytophthora* rot of fruits (40-50%) at Rajendranagar (Telangana) besides early blight and *Fusarium* wilt.

Rabi tomato had 40-50% severity of late blight in the 3rd week of March (12th SMW) at Patiala (PB). Increasing target leaf spot incidence with increasing maximum temperature and decreasing relative humidity of December, and decreasing early blight with increasing minimum temperature and morning relative humidity of February were noted at Kalyani (WB).

Prediction rules based on weather criteria and pest severity levels were developed for brown plant hopper *Nilaparvata lugens* of Raipur (Chhattisgarh), Ludhiana (Punjab) and Aduthurai (Tamil Nadu), and for early leaf blight at Bengaluru (KA).Use of ordinal logistic model for the population dynamics of *S. litura* on groundnut at Dharwad (Karnataka) indicated the odds of *S.litura* being 'high'(>400 moths/trap/week) (as opposed to low or medium) increased by a multiple of 8.6 with each degree increase in maximum temperature during 32 SMW, as compared to 6.4 times with odds of being high or medium (as opposed to low) with relative humidity, the prediction accuracy being 68%.The empirical models developed for yellow stem borer (*Scirpophaga incertulas*(Walker)) and leaf folder (*Cnaphalocrcis medinalis* (Guenee)) of rice for Aduthurai (Tamil Nadu), Chinsura (West Bengal), Karjat (Maharashtra), Mandya (Karnataka), Ludhiana (Punjab) and Raipur (Chhattisgarh) locations were web enabled @ http://172.16.30.80:8080/WebApplication2/CSSTEMPLATE/dh1269/index.html Web enabled weather based predictions for four rice pests (yellow stem borer, gall midge, case worm and green leaf hopper), and *S. litura* on groundnut at weekly and fortnightly basis predicting maximum severity of *S. litura* forewarned low severity in 100% of the occasions during *Kharif* 2014.

Trend Analysis

Trend analysis was done weather variables and *S. litura* pertaining to *Kharif* groundnut season of Dharwad district of Karnataka using Mann-Kendall non parametric test before the development of ordinal logistic prediction model. Significantly increasing trends of average and minimum temperatures and rainfall, and decreasing trend of morning and evening relative humidity and their mean were seen. Chi-square score testing proportional odds assumption and Akaike Information Criterion (AIC) and Schwarz Criterion (SC) testing the adequacy of the model indicated that the maximum temperature and morning relative humidity prior to two weeks contribuing significantly to the high level of *S. litura*. It was inferred that for each degree of increase in maximum temperature during 32 SMW, the odds of *S.litura* being 'high'(>400 moths/trap/week) (as opposed to low or medium) increased by a multiple of 8.6 as compared to 6.4 times with odds of being high or medium (as opposed to low) with relative humidity. The validation of the model done in terms of percent concordance and discordant between association of predicted probabilities and observed responses indicated 68% accuracy.

Heuristic weather based criteriabased on light trap catchesofbrown plant hopper, *Nilaparvata lugens* Stal.*viz.,*weekly mean temperature (22-28°C), relative humidity (60-80%), sunshine hours (8-9 hr/day), wind speed (0-5 km/day) and total rainfall (d" 25 mm) for Raipur (CG), and weekly mean temperature (26-28°C), relative humidity (65-75%), sunshine hours (8-10hr/day), wind speed (0-5 km/day) and total rainfall (d" 25 mm) for Ludhiana (PB) predicting the severity *viz.,* low (< 200), medium (200-1000) and high (> 1000)was developed. For Aduthurai (TN), the weather based criteria are the

weekly mean temperature (24-28°C), relative humidity (>78%), sunshine hours (8-9 hr/day), wind speed (0-6km/day) and total rainfall (d" 25 mm) that predict the low (< 100), medium (100-500) and high (> 500). In all the above three locations, satisfying more than three, three and less than three out of five weather based criteria would predict high, moderate and low severity, respectively. Mean accuracy of prediction over the last two seasons (2013 and 14) across locations was 90%. Weather parameters prior to two weeks *viz.,* maximum tempertaure of 25-30 °C, minimum temperature of 18-21 °C, morning relative humidity e" 80%, evening relative humidity e" 50%, rainfall e" 5mm with sunshine hours d" 4 hours together with the current crop age e" 60days predicting high (e"50%), moderate (21-49%) and low (d" 20%) early blight severity on tomato at Bengaluru (KA) under the conditionality of more than four, four and less than four rules being fulfilled, respectively was formulated and tested with >85% accuracy.

Web enabling of the forecast system

A web based forewarning system was developed for yellow stem borer (*Scirpophaga incertulas*(Walker)) and leaf folder (*Cnaphalocrcis medinalis* (Guenee)) of rice for different locations *viz.,* Aduthurai (Tamil Nadu), Chinsura (West Bengal), Karjat (Maharashtra), Mandya (Karnataka), Ludhiana (Punjab) and Raipur (Chhattisgarh) for the developed forecast models (refer 2013-14 Annual report). The system was developed based on 3-tier architecture consisting of Client Side Interface Layer (CSIL), Application Logic Layer (ALL) and Database Layer (DBL). CSIL was implemented by HTML (Hyper Text Markup Language), CSS (Cascading Style Sheet) and JavaScript (for validation purpose). ALL has been implemented by the JSP (Java Server Pages) technology which provides a framework to create dynamic content on the server. Location and time specific pest forecast models have been coded in this language was saved on the server. Data Base Layer was used for storing the site and time specific weather related data. In this system, only administrators have the provision of feeding the weather information into the database. The utility of the forecast system requires the users to know beforehand the time period of forecast and timely access for its success.

Web enabled weather based predictions for four rice pests (yellow stem borer, gall midge, case worm and green leaf hopper), and *S. litura* on groundnut at weekly and fortnightly basis predicting maximum severity of *S. litura* forewarned low severity in 100% of the occasions during *Kharif* 2014.

Pest dynamics in relation to climate variables in Mango (ICAR-RCER)

Strategies for pest forewarning and minimization of pest incidence in mango under changing weather scenario can be attempted through better understanding of host-pest-climate interaction. Under the project, observation of data on Real Time Pest Dynamics was recorded at weekly interval from 120 mango orchards in six different mango growing

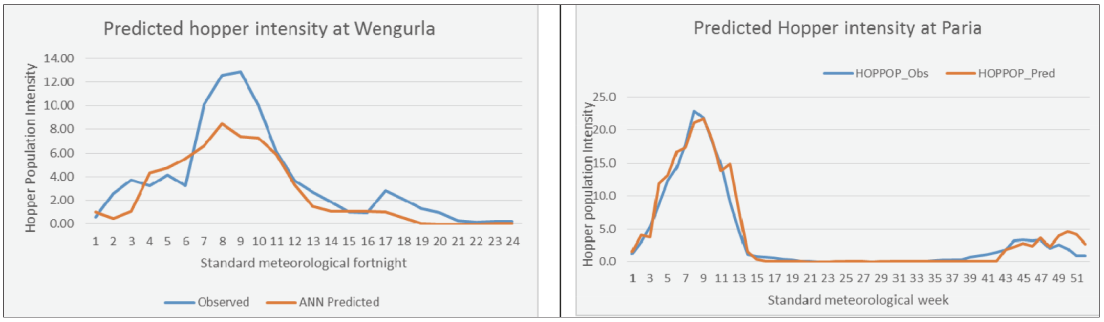
belt viz. Ranchi in Jharkhand, Lucknow in Uttar Pradesh, Vengurla in Maharastra, Paria in Gujarat, Sangareddy in Andhra Pradesh and Bangalore in Karnataka. Based on the data on RTPD, correlations between pest incidence and weather parameters have been estimated which varied among different states.

From survey of insect pest, first report of pyralid fruit borer, *Citripestis eutraphera* (Meyrick) in Indian main land was recorded on immature mango fruits from several villages of rural Bangalore and parts of Karnataka during April-June, 2013 . Further, surveys were also carried out in off-season mango growing belts of Tamil Nadu viz., Kanyakumari, Thirunelveli districts during October, 2013. Report about the spread of this restricted pyralid borer into Karnataka and Tamil Nadu is not quite alarming.

Infested fruits by pyralid fruit borer, *Citripestis eutraphera*

From real time pest dynamics surveillance data, high incidence of blossom blight was observed in Uttar Pradesh and Jharkhand mango orchards in 2015. The disease results in burning of the full bloom panicles and causes significant loss. The overall observed percent disease intensity (PDI) of disease was 45.24% in Jharkhand and 90.0% (Severity 5.0) in Uttar Pradesh orchards in entire fixed and roving surveyed orchards. The incidence of disease started due to abrupt changes in weather phenomena specially rainfall. High incidence of mango hoppers at the time of panicle initiations to fruit setting was observed during flowering of mango in Jharkhand conditions. Early increase of mean temperature lead to early incidence and successive high population build up of hopper on mango this year in region and population above ETL depicted thorough Hot spot location on map through ArcGIS software.

The artificial neural network (ANN) technique was evaluated for its applicability for forecasting of incidence of mango hoppers under increasing temperature scenarios in Konkan region of Maharashtra and Valsad region of Gujarat. Two models with different architecture were developed for Vengurla and Paria station datasets. The model simulated time series matches the observed hopper population intensity most closely in case of Vengurla and Paria stations. Comparison of observed and simulated time series suggested that the neural computing technique could be employed successfully in modelling the hopper population from the available climatic data set

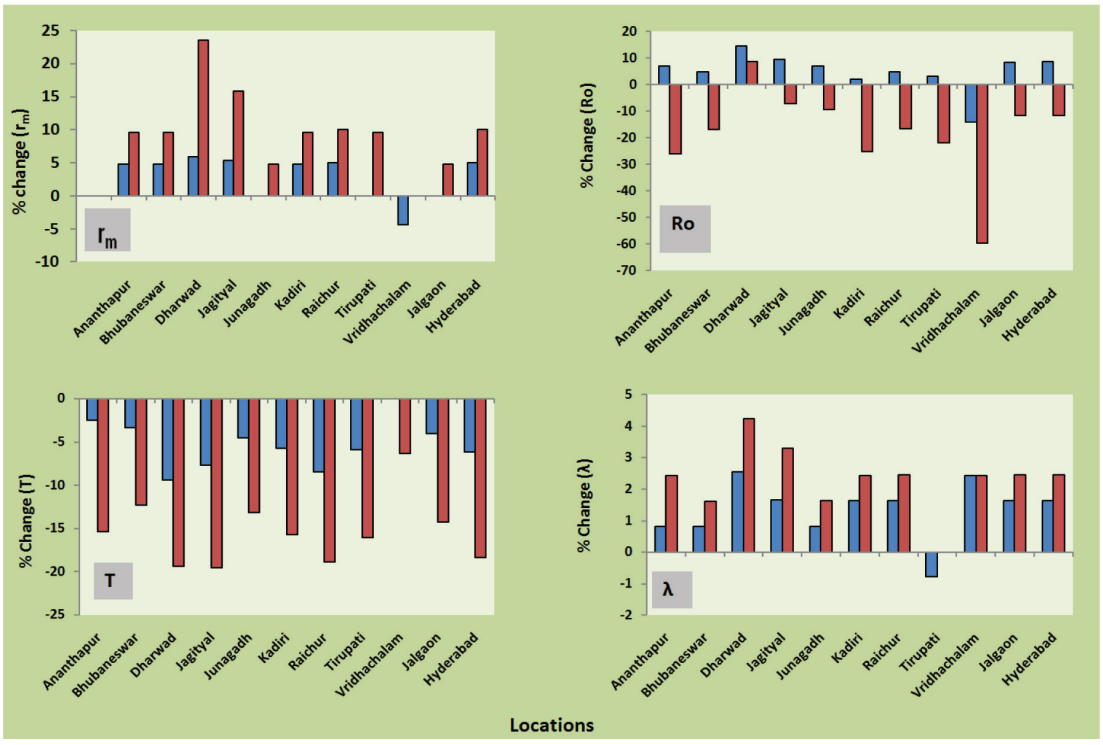


Observed and simulated mango hopper population through ANN based modeling based on historical data of two stations

Prediction of pest scenarios of *Spodoptera litura* Fab. on peanut using Life table approach (CRIDA)

Studies were conducted to understand the direct effects of rising temperature and host – mediated effect of elevated CO_2 (eCO_2), on *Spodoptera litura* (Fabricius) (Noctuidae: Lepidoptera). This study involved **i.** the construction of life tables of *S. litura* reared on peanut (*Arachis hypogaea* L.) grown under 380 ppm ambient CO_2 (aCO_2) and 550 ppm elevated CO_2 (eCO_2,) at six constant temperatures viz., 20, 25, 27, 30, 33 and 35 °C ± 0.5°C **ii.** Estimation of threshold temperatures and thermal constants and **iii.** Prediction of the pest scenarios during near and distant future climate change periods. The mean development time (days) of each stage, egg, larva, pupa, pre-oviposition and total life span decreased with increase in temperature from 20 to 35°C. The thermal requirement of *S. litura* from egg to egg (within the range of 20°C to 35°C) was 538.50 DD in larvae fed with eCO_2 foliage as against 494.51 DD in larvae fed with aCO_2 foliage. Finite (ë) and intrinsic rates of increase (r_m), net reproductive rate (Ro), mean generation time (T) and doubling time (DT) of *S. litura* varied significantly with temperature and CO_2 and were found to have quadratic relationship with temperature.

The data on life table parameters were plotted against temperature and two non-linear models were developed for the two CO_2 conditions and used for predicting the pest scenarios based on PRECIS A1B emission scenario data at eleven peanut growing locations of the country during near future (NF) and distant future (DF) climate change periods. Results showed increased 'r_m' and 'ë' with variable 'R_o' and reduced 'T'. The results of per cent change in predicted life table parameters during NF and DF scenarios over baseline are depicted. The per cent change in 'r_m' was higher at majority of the locations in both NF (up to 6%) and DF (up to 23%) scenarios. The 'R_o' is expected to increase moderately in NF (14%) and decrease in DF (-26-60 %) scenarios at all locations. Reduction of generation time 'T' is expected to be higher in DF (19%) than NF scenario (1-9%). At majority of locations, ë was expected to increase in both NF and DF periods. These results suggest that temperature and CO_2 are vital in influencing the growth and life table parameters of *S. litura* and that pest incidence is likely to be higher in the future.

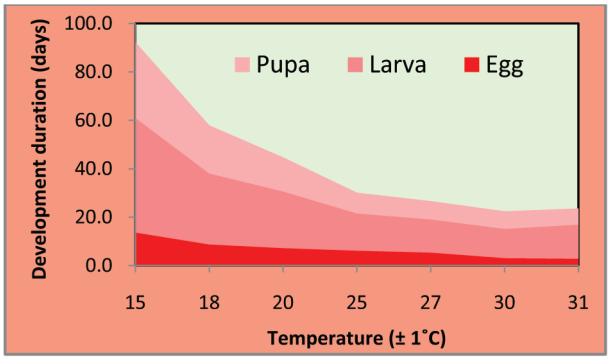


Per cent change over baseline in pest scenarios during near and distant future climate change period

Studies on pest population dynamics (CRIDA)

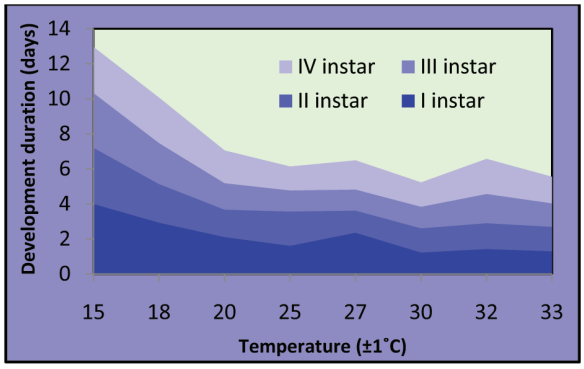
a) Effect of temperature on development of insect pests

Pigeonpea hairy caterpillar: The development of the hairy caterpillar *Euproctis subnotata* (Walker) was studied at seven constant temperatures, viz., 15, 18, 20, 25, 27, 30, 31 and 33±1°C. Developmental durations of egg, larva, pupa showed linear decreasing trend till 30°C and nonlinear response was observed at 31°C for total larval period. At 33°C egg hatching was not observed and development of larval stage ceased at IV instar. Developmental duration was longer at 15°C.



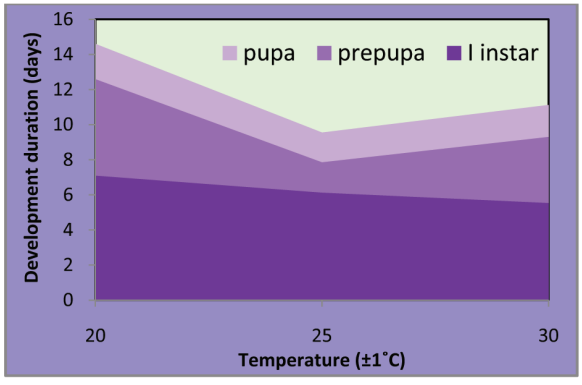
Development duration of immature stages of *hairy caterpillar* at different constant temperatures

Maize aphid: The effect of temperature on the development, survival and fecundity of maize aphid *Rhopalosiphum maidis* (Fitch) was studied at eight constant temperatures 15, 18, 20, 25, 27, 30, 32 and 33±1^{0}C on maize leaves. Total nymphal development showed a linear decreasing trend till 25°C and a nonlinear response was observed at 27^{0}C. Longest developmental period was observed at 15^{0}C (12.96 days) and shortest was observed at 30^{0}C (5.1 days).



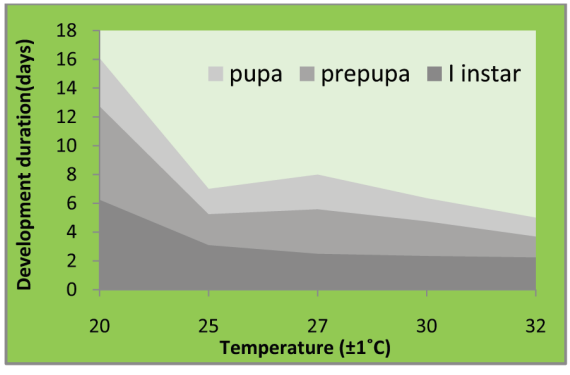
Development duration of immature stages of maize aphid at different constant temperatures

Groundnut thrips (*Scirtothrips dorsalis*): Thrips *(Scirtothrips dorsalis)* development on groundnut was studied at three different constant temperatures viz., 20, 25 and 30°C. Developmental duration decreased with increase in temperature for 1st instar, whereas for pre pupal, pupal and total nymphal periods non linear relation was observed at 30°C.



Development duration of *Scirtothrips dorsalis* at different temperatures

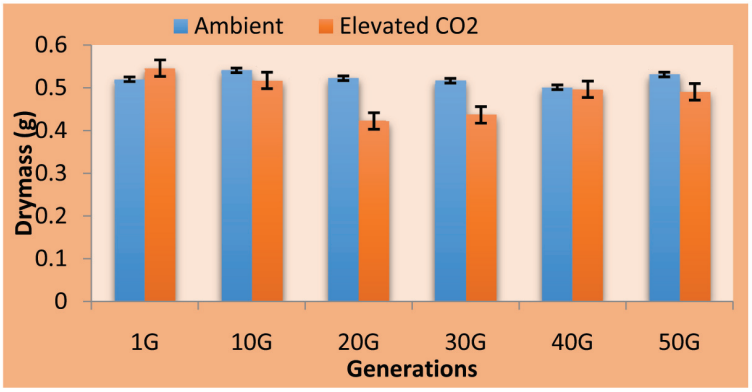
Groundnut thrips (*Caliothrips*): Thrips *(Caliothrips)* development on groundnut was studied at five different constant temperatures viz., 20, 25, 27, 30 and 32°C. Developmental duration decreased with increase in temperature for 1st instar, whereas for pre pupal, pupal and total nymphal periods non linear relation was observed at 27°C.



Development duration of groundnut thrips *(Caliothrips)* at different constant temperatures

Impact of climate change on plant pathogens (CRIDA)

Effect of 550 ppm levels of CO_2 and temperature were studied on *Sclerotium rolfsii*, a devastating soil-borne plant pathogen infecting several field crops. Observations were recorded on variability in biomass, morphology and pathogenicity over 50 generations (G), at an interval of 10G. These studies were carried out in 250 ml flasks, inoculated with 5 active sclerotia and incubated for 15days. The biomass was collected and dried in hot air oven until constant mass of the pathogen. Even after 50 generations, there was no significant change in drymass. Similarly the exposure to 550 ppm levels of CO_2 did not significantly alter the size of scelrotia, which ranged from 0.8 to 1 mm.



Effect of CO_2 on drymass of *sclerotium rolfsii* over generations

Pot studies were carried out to study the pathogenicity of *Sclerotium rolfsii* over generations from 1st to 50th G with an interval of 10G under ambient (380 ppm) and elevated CO2 (550 ppm) conditions. Groundnut cv. Narayani was used for the experiment. Pots were filled with sterile soil and 3% redgram (leaf + stem) powder to serve as organic matter. Five sclerotia per seed were added and the seeds were sown to assess the rate of southern blight. Rate of sclerotial germination was checked, before the onset of the studies. Disease progress was recorded over time. The infection started earlier in cultures exposed to elevated CO_2 i.e. by 3rd day itself whereas in control, the infection started by 6th day. However, by 12th day, disease progress became uniform across generations.

Influence of elevated Carbon dioxide on Brown plant hopper (DRR)

Experiments were carried out to know the impact of elevated CO_2 on the biology of BPH. The survival and development of BPH was studied by exposing the insects at three levels of CO_2 (550ppm (*e* CO_2) with temperature control (29.0±0.3°C), RH (70±5%), 550ppm (*e*CO_2) without temperature control (31.0±0.3°C), RH (63±5%) and 380ppm (*a*CO_2) and temperature (28.0±0.3°C), RH (70±5%) concentrations continuously. A Closed Dynamics CO_2 Chamber (CDCC) was used as CO_2 control system. The population of *Nilaparvata lugens* was collected from two locations of India (West Godavari and Punjab). These populations were reared continuously on susceptible rice TN1 in glasshouse were continuously exposed to different CO_2 levels in a closed CO_2 chambers upto 6thgeneration. Observations were recorded on total nymhal duration, adult emergence, adult longevity, fecundity and adult life span. Among all the treatments less developmental duration and higher fecundity was noticed at *e*CO_2.

Influence of climate change on generations of *Spodoptera litura* (IIHR)

CLIMEX based pest distribution modeling (South American Tomato leaf miner, *Tuta absoluta*)

Current and potential future distribution of South American tomato leaf miner, *Tuta absoluta* under climate change scenarios (1°C and 2°C rise in temperature) was assessed using CLIMEX. The gradual decline in marginal and suitable areas for *T. absoluta* establishment is evident under 1^0C or 2^0C. Among the parameters used for the sensitivity analysis, upper temperature threshold and upper soil moisture threshold showed high sensitivity to change in Ecoclimatic Index for *T. absoluta*.

Ecoclimatic Index (EI) scores suggest that the climate is favorable for the establishment of the pest in most parts of India. Regions like Rajasthan, Gujarat, few parts of Maharashtra and Andhra Pradesh are expected to be unsuitable for the pest due to prevailing heat and dry stress. Due to cold stress, parts of Uttarakhand, Arunachal Pradesh and Jammu & Kashmir are expected to be unsuitable for *T. absoluta*

A gradual increase in the suitability range for the pest establishment is predicted under two probable temperature regimes devised in the present analysis (1^0 and 2^0 C increase in global temperature) in temperate regions of India. An overall decrease in suitability is observed due to increase in heat and dry stress. However parts of southern India, North eastern states and northern belts still favours the establishment of the pest.

Using compare locations of CLIMEX, the current and future potential distribution (1^0C rise in temperature) of *P. marginatus*, a major pest on papaya and a minor pest on tomato was assessed for Indian conditions. The current climatic conditions are favorable for the pest in most regions of south, eastern, and few parts of northern India. The magnitude of the suitability is expected to decline gradually in India under the projected elevated temperature regime. Under climate change of 1^0C rise in temperature, many tropical regions in central and western India are expected to become unsuitable for the survival of the pest. Suitability is expected to increase in north eastern states, and northern India due to the decrease in cold stress.

Effect of eCO_2 (550 ppm) and ambient CO_2 (380 ppm) at 32^0C on Development of insects/mites

Developmental studies on two spotted spider mite, *Tetranychus urticae* under elevated CO_2 conditions indicated that proportionately more females (4:1) were observed under elevated CO_2 when compared to ambient conditions. On tomato, glandular, type I and VII and non- glandular type V trichomes increased at elevated CO_2 (550 ppm). Significant increase in feeding (%) in mango stone weevil males was observed when compared to females at 550 ppm CO_2.

Tomato fruit borer, *Helicoverpa armigera* showed slower developmental rate under elevated CO_2 levels. Larval and pupal developmental duration was 1-2 days more under elevated conditions compared to ambient. Egg to pupal development of American serpentine leaf miner, *Liriomyza trifolii* took 15 days under ambient and 16 days under eCO_2 (550 ppm) condition. Differential endosymbiont bacterial diversity was observed at heat stress and cold stress in mango fruit fly, *Bactrocera dorsalis*. The salicylic acid treatment on tomato plants resulted in lower incidence of mites.

Impact of climate variables on pollinators (IIHR, UAS)

Climate change has a significant impact on pollinators, particularly in fruit and vegetable crops. A detailed study was taken up covering apple, mango, water melon, mustard and coffee at different locations across the country by IIHR, UAS, TNAU, YSPUH&F and GBPUA&T. The salient findings are given hereunder:

Pollinator diversity and shifts in relation to temperature: The diversity and abundance of pollinators were recorded from major mango belts (Andhra Pradesh, Karnataka, Tamil Nadu, Maharashtra, Uttar Pradesh) of the country and correlated with temperature. The trend in the pollinator activity during 2011-12 to 2014-15 revealed notable variations in the abundance. While Indian little bee, *Apisflorea* showed significant negative correlation ($r = -0.63$) with temperature during blossom period, calliphorid, *Chrysomyamegacephala* and syrphids had no significant correlation. These findings were further confirmed by the observation that the activity of *A. florea* declines at temperatures beyond 30°C while *C. megacephala* remains unaffected masking it a desirable species under high temperature regimes.

An interesting observation was made that the effect of temperature on pollinators in mango was also mediated through the extent of bisexual flowers in a variety. The proportion of bisexual flowers varied significantly among varieties and increased temperature enhances the proportion of hermaphrodite flowers. Significant correlations were found between the per cent bisexual flowers and pollinator species on a particular variety.

Among the species tested, *C. megacephala* was found to be the most efficient pollinator of mango. Fruit set (cv. Banganapalli) was highest in trees exposed to *C. megacephala* (35.4/panicle) and on par with open pollination in other varieties.

Effects of climate change on pollinator population (UAS)

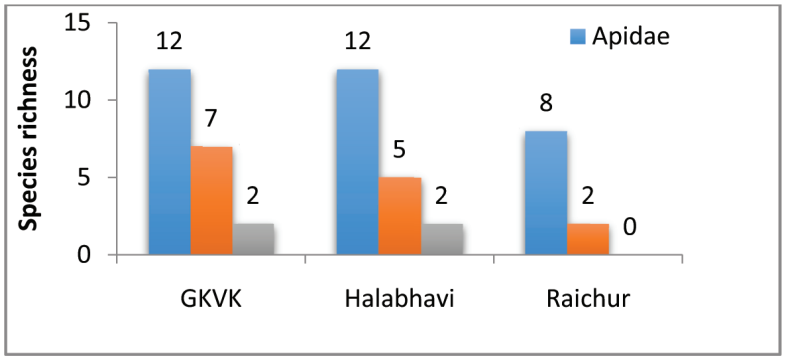
Studies on the effects of climate change on pollinator populations were made in four centres spread in different parts of the country, each center concentrating on one or more crops. The centers included UAS, Bangalore which concentrated on studies on cardamom and coffee at Mudigere and on sunflower at Bangalore; TNAU, Coimbatore (on populations of Apis dorsata and on pollination of sunflower); GBPUAT, Panthnagar (on sunflower and mustard) and YSPUHF, Solan (on apple and mustard). Detailed

observations on the pollination biology of these crops and the possible effects on changing climatic conditions on the pollination efficiency and on the pollinator diversity and abundance were recorded.

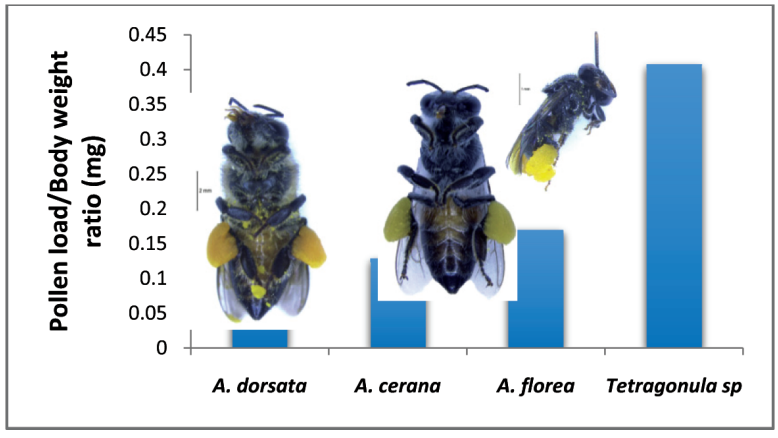
Flowering phenology and pollinator diversity

Flowering phenology and pollinator diversity was assessed on five crops viz., sunflower (Bangalore, Coimbatore, Panthnagar), mustard (Solan, Panthnagar), cardamom (Bangalore: Mudigere), coffee (Bangalore: Mudigere) and apple (Solan, Kullu). Historical weather data from different study sites have been collected to relate the effects of temperature and rainfall on the flowering phenology and/or the activity of flower visitors. In all the crops being studied basic information on role of flower visitors and the most potential pollinators have been identified.

Climate change can result in alteration in flowering time and the availability of pollinators. In view of this, attempts were made to create simulations with varying SD and Mean values for both flowering time and pollinator activity. Using field data from flowering phenology and pollinator activity, the model developed was validated for Cardamom.



Species richness of bees on sunflower at GKVK, Halabhavi and Raichur



Pollen carrying efficiency of major bee pollinators (Pollen load/Body weight ratio) (GKVK, Bangalore); Smaller the bee the higher its pollen load capacity

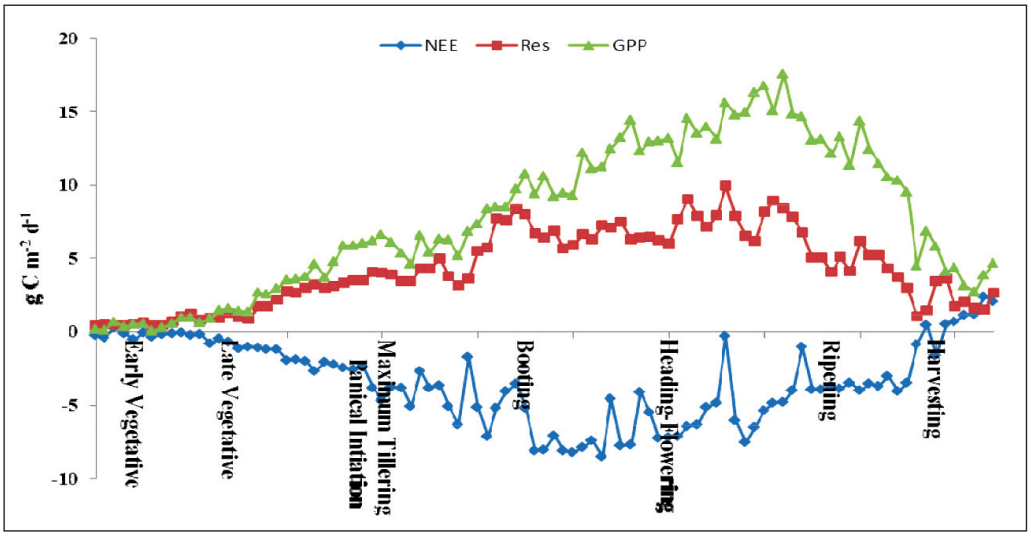
4.5 Adaptation and Mitigation through Soil, Water and Nutrient and Energy use Efficiency

Efficient management of natural resources such as soil, water and nutrient etc are key to climate change adaptation and mitigation. Several institutes of ICAR, SAU's and IIT have participated in this multi-disciplinary theme on adaptation and mitigation.

Measurements of GHG emissions using Eddy-Covariance technique (IARI)

Measurement of GHG fluxes (carbon dioxide and methane), moisture and heat in the soil-plant-atmosphere systems using the Eddy Covariance technique was carried out in rice-wheat rotation. The net ecosystem carbon dioxide exchange (NEE) and net ecosystem methane exchange (NEME) were monitored in rice and wheat crops and also during the fallow season. The gross primary productivity (GPP) and NEE was found to be highest between heading to ripening stage in rice whereas it was maximum at flowering stage in wheat.

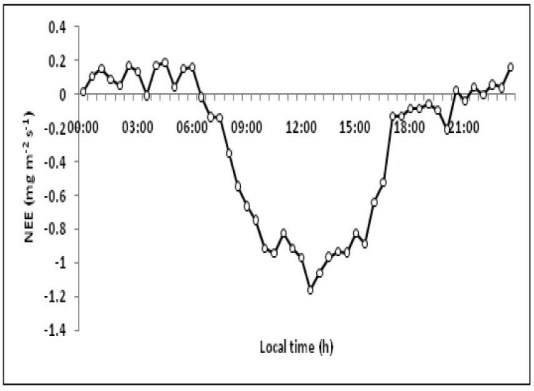
The net ecosystem methane exchange (NEME) during rice growth period was found to be highest between active tillering to maximum tillering stage in rice. The seasonal cumulative flux of methane was observed to be 2.61g m^{-2} during the 96 days of rice, Pusa 1509 crop growth. The average diurnal methane emissions were estimated for the entire crop growth period and it was observed that maximum emissions of methane occurred between 12.30 to 2.30 pm.



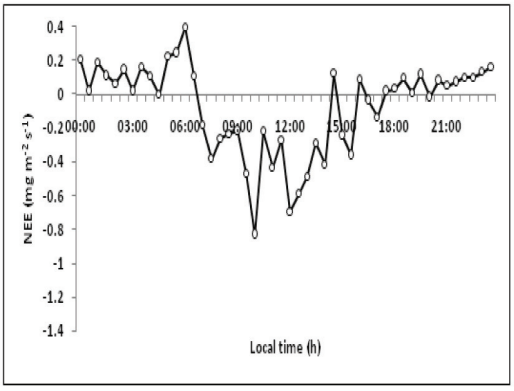
Gross primary productivity and NEE in rice

Characterization of net ecosystem carbon dioxide and methane exchange (CRRI)

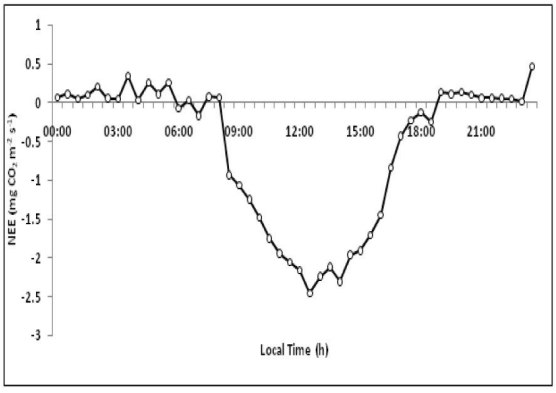
The diurnal variations in mean Net Ecosystem Exchange (NEE) in submerged rice ecosystem in both the dry and wet seasons, varied from +0.2 to -1.2 and +0.4 to -0.8 mg CO_2 m^{-2} s^{-1}, respectively. The NEE ranged between +1 to -3 mg CO_2 m^{-2} s^{-1} at active tillering stage, +0.5 to -2 mg CO_2 m^{-2} s^{-1} at maximum tillering stage, +0.4 to -1.4 mg CO_2 m^{-2} s^{-1} at panicle initiation stage and varied from +0.4 to -1 mg CO_2 m^{-2} s^{-1} at harvesting stage during the dry season.



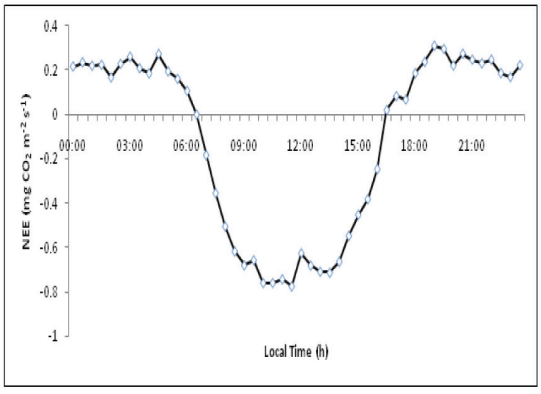
Diurnal variations in mean NEE in dry season, 2014



Diurnal variations in mean NEE in wet season, 2014



Diurnal variations in mean NEE at active tillering stage during dry season, 2014



Diurnal variations in mean NEE at harvesting stage during dry season, 2014

Elevated CO_2 and temperature & GHG emissions from chickpea (IARI)

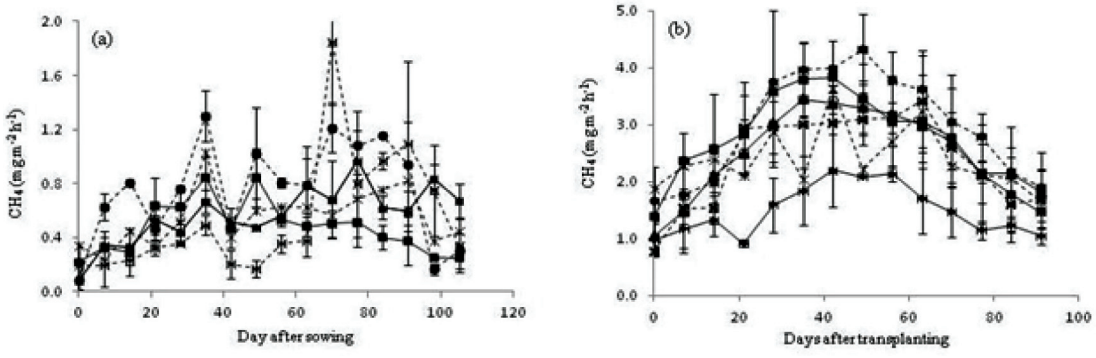
Elevated CO_2 (ambient + 500 ppm) significantly increased carbon dioxide emission from soil under chickpea whereas no significant increase was observed in nitrous oxide emissions. However, elevated temperature (ambient + 1.5°C) significantly increased N_2O emissions, leading to an increased global warming potential (40%) under the interaction treatment. The chickpea yield also increased under the interaction treatment.

Effect of climatic variables on global warming potential in chickpea

Treatment	CO_2 emission (kg/ha)	N_2O emission (g/ha)	GWP (CO_2 kg/ha)
Control	1653a	448a	1792a
Elevated Temp	2238b	524c	2400b
Elevated CO_2	2200b	468a	2345b
Elevated Temp + CO_2	2382b	510bc	2540b

Nitrogen management strategies for mitigation of GHG emissions from soils in direct seeded aerobic and transplanted continuously flooded rice (CRRI)

A field experiment with rice variety Apo (IR 55423-01) was conducted with N treatments viz. 0 N (T1), 100 kg N ha^{-1} as prilled urea (PU), applied through conventional method (T2), 100 kg N ha^{-1} as neem coated urea (NCU), applied through conventional method (T3), 100 kg N ha^{-1} as PU, applied on the basis of customized leaf colour chart (CLCC) reading (T4), 100 kg N ha^{-1} as NCU, applied on the basis of CLCC reading (T5), and 100 kg N ha^{-1} as PU and farm yard manure (FYM) in 1:1 ratio applied through conventional method (T6). The results of this study revealed that the fluxes of CH_4 varied from 0.07 to 1.8 mg m^{-2} h^{-1} in aerobic rice (AR) and from 0.77 to 4.8 mg m^{-2} h^{-1} in continuously flooded rice (CFR). The highest CH_4 flux was recorded during panicle initiation (PI) (41-49 DAT) stage in CFR. The cumulative seasonal CH_4 emission was reduced by75% in AR as compared to CFR. The lowest seasonal CH_4 emissions (11.4 kg ha^{-1} in AR and 34.1 kg ha^{-1} in CFR) were recorded in treatments, where no N was applied (T1). Inclusion of FYM along with PU enhanced CH_4 emission in CFR significantly, where as the highest emission was recorded in T6 followed by T2.

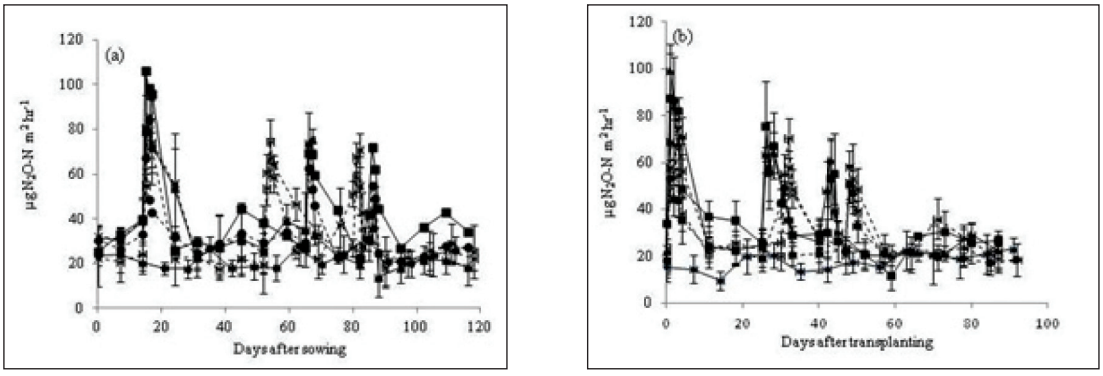


Seasonal variations in CH_4 emission from aerobic rice (a) and continuous flooded rice (b)

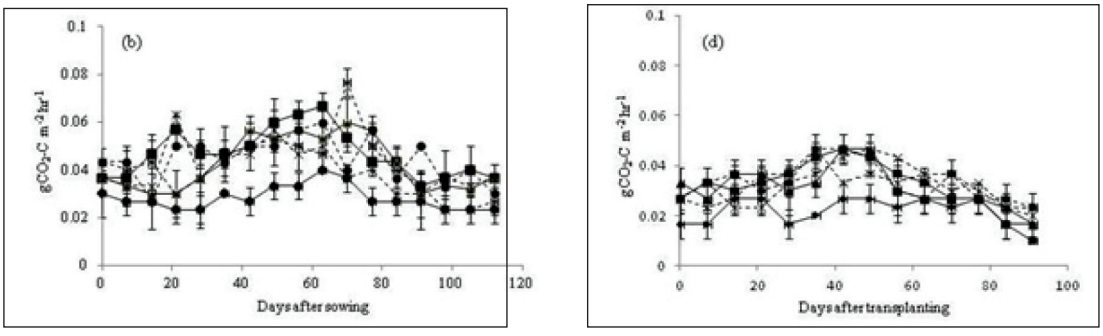
The flux of N_2O-N varied from 11.9-105.8 µg N_2O-N m^{-2} hr^{-1} in AR and from 6.2-98.9 µg N_2O-N m^{-2} hr^{-1} in CFR. The peaks were observed within 2-3 days after N application.

The mean seasonal N_2O-N emission was 37% more in AR than in CFR. The cumulative seasonal emission varied from 0.57 to 1.01 kg N_2O-N ha^{-1} in AR and from 0.39 to 0.67 kg N_2O-N ha^{-1} in CFR. The seasonal emissions were in the order of T2=T4>T6=T3=T5> T1 and T2> T3>T5>T4>T6>T1 in AR and CFR, respectively.

The CO_2 flux from soil ranged from 0.02 to 0.08 g CO_2 m^{-2} hr^{-1} in AR and from 0.01 to 0.05 g CO_2 m^{-2} hr^{-1} in CFR. The fluxes were peaked between 49 to 63 DAS in AR and between 42 to 49 DAT in CFR. Nitrogen application wise seasonal CO_2 emission ranged from 768-1116 kg ha^{-1} in AR and 497-686 kg ha^{-1} in CFR. Higher CO_2 emission was recorded with inclusion of FYM along with PU (T6) as compared to PU alone (T2) in AR Treatment with no N recorded lowest seasonal CO_2 emission in both the moisture regimes.



variations in N_2O-N emission from aerobic rice (a) and continuous flooded rice (b)



Seasonal variations of CO_2 flux in aerobic direct seeded rice (b) and transplanted rice (d)

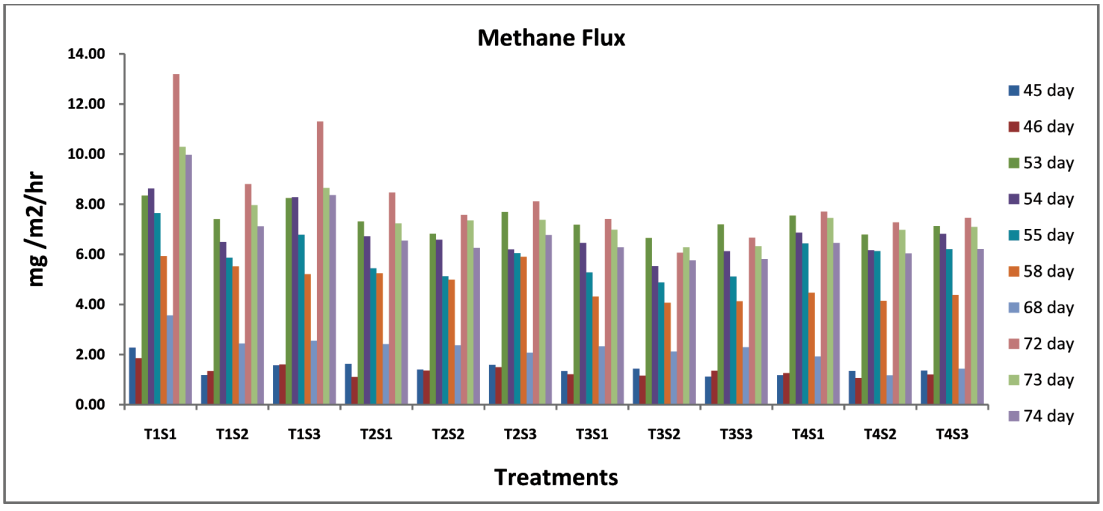
Global warming potential (GWP) was computed from CH_4, N_2O and CO_2 efflux values by following formula i.e. GWP= 24.5 x CH_4 (kg ha^{-1}) + CO_2 (kg ha^{-1}) + 320 x N_2O (kg ha^{-1}). Greenhouse gas intensity (GHGI) was calculated by dividing GWP by grain yield. The GWP ranged from 1313 to 2111 kg CO_2-equivalent ha^{-1} in AR and from 1516 to 2659 kg CO_2-equivalent ha^{-1} in CFR. The highest GHGI was observed in T1 of AR and the lowest was in T5 of CFR.

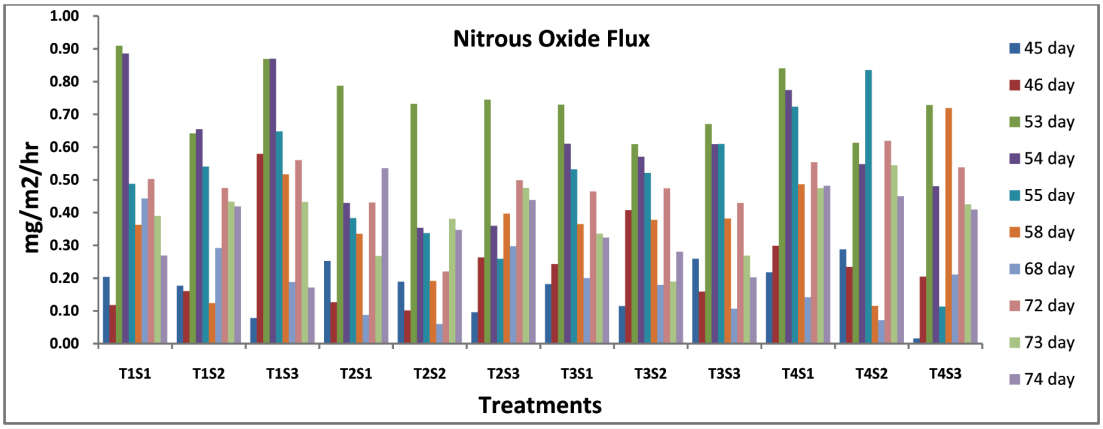
Mitigating greenhouse gas emission in rice-wheat system with crop diversification (IARI)

Earlier studies conducted at this site showed that intermittent flooding, growing short duration variety and leaf-colour chart-based nitrogen application with nitrification inhibitor could reduce the emission by 25-30%, 15-20% and 10-12%, respectively, compared to conventional puddled, continuously flooded rice. In case of wheat leaf colour chart-based nitrogen application with nitrification inhibitor could reduce emission by 18-20%.The emission can be drastically reduced by 60-70% with crop diversification from rice-wheat to maize-wheat system. In the maize-wheat system again, neem oil coated urea and dicyndiamide (DCD) reduced the global warming potential by 10-15% and increased grain yield by 4-5% over the conventional practices.

GHG measurement under different crop establishment methods and different sources of Nitrogen under rice-wheat system (IIFSR)

Experiments were conducted for GHG measurement under different crop establishment methods and different sources of nitrogen under rice-wheat system. During the first year of experimentation (2014-15), maximum methane flux was noticed under transplanted puddled rice with normal urea application compared to all other treatment combinations at different stages of the rice crop. The highest methane flux occurred at 72 days after sowing in all the treatment combinations. There was 54 % reduction in methane flux under aerobic+neem coated urea (T3S2) followed by 49 % reduction in aerobic+sulphur coated urea (T3S3) compared to conventional puddling+normal urea application. The highest nitrous oxide flux occurred at 53 days after sowing in all the treatment combinations, except in case of SRI+neem coated urea (T4S2). There was 33 % reduction in nitrous oxide flux in aerobic+neem coated urea combination (T3S2) and in SRI+neem coated urea (T4S2) compared to conventional puddling+ normal urea combination treatment.

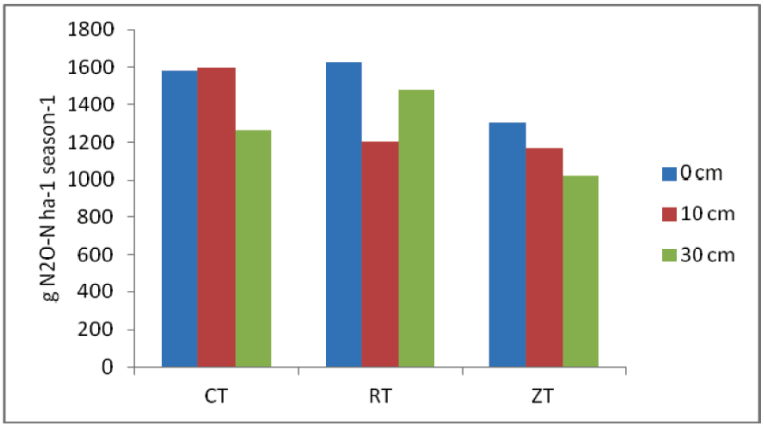




Methane and nitrous oxide flux(mg/m2/hr) recorded under different establishment methods Vs source of nitrogen in rice

GHG emissions from rainfed production systems (CRIDA)

Green house gas fluxes in Conservation Agriculture systems



Seasonal fluxes of CO_2, CH_4 and N_2O in different tillage and residue management practices in pigeonpea-castor system

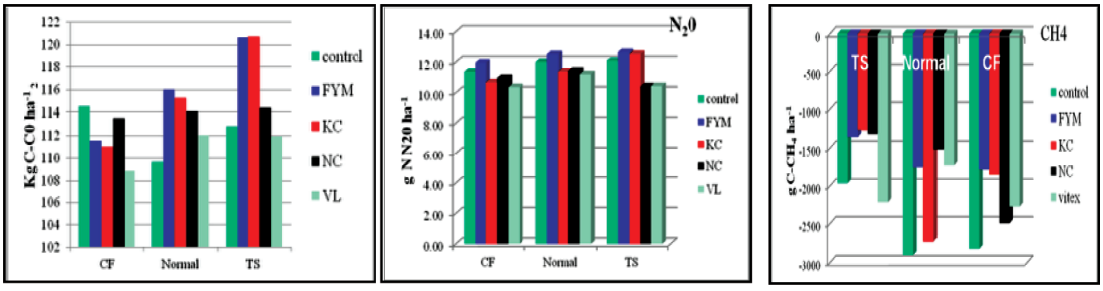
Results on conservation agriculture revealed that CO_2, CH_4 and N_2O fluxes were influenced by tillage and anchored residue. The ZT recorded 8 % higher CO_2 fluxes as compared to CT and RT. The CO_2 measurements done after off season tillage and rainy season tillage just after ploughing was found to increase CO_2 flux immediately after tillage and this increase was only for few hours and decreased later. Higher CO2 emissions were observed in tilled plots for four days. The CT has recorded 22 % higher N_2O emissions as compared to ZT. The higher N_2O emissions under CT could be due to a strong disaggregation and enhanced soil aeration, which help in improving the living conditions of aerobic nitrifying bacteria. Influence of crop residues on GHG emissions is more pronounced in ZT than in CT and RT. Anchored residues of 10 and 30 cm in ZT reduced the N_2O emissions whereas in CT significant difference in

emissions between residues was not observed. In all the treatments, both release and uptake of methane was observed.

Influence of natural nitrification inhibitors in Castor-Maize based cropping system (CRIDA)

GHG emissions in castor-maize cropping system were measured in different moisture conservation practices viz., control, conservation furrow, and tank silt application as well as natural (plant based) nitrification inhibitors like neem cake coated urea, Karanjin cake coated urea and vitex leaf coated urea. These treatments were compared with urea and 50% nitrogen through FYM + 50 % N through urea.

The CO_2 fluxes were not influenced by moisture conservation methods and nitrification inhibitors but relatively lower CO_2 fluxes were observed in urea as well as vitex coated urea in castor crop. In all the treatments methane absorption was observed and N_20 fluxes were higher immediately after fertiliser application as urea. N_20 fluxes were lower in vitex cake coated urea followed by neem cake coated urea as compared to urea alone.



Influence of different moisture conservation methods and NNI coated urea on GHG emissions

Adaptation and mitigation through water management

Impact of climate change on water productivity and water footprints of groundnut (IIWM)

In this investigation, DSSAT 4.5 model was calibrated and evaluated to study the effect of elevated temperature and carbon dioxide and their interaction on crop duration, growth and productivity of groundnut crop. The results of this study showed that under elevated temperature in 2070 as per IPCC RCP 4.5 scenario, crop duration was reduced by 7 days under both 370 ppm (current) and 550 ppm CO_2 concentrations. Yield and yield components were negatively affected by increase in temperature under both 360 ppm and 550 ppm CO_2 scenarios. However increase in CO_2 concentration from 370 to 550 ppm had some promotive effect on maize productivity. The reduction in simulated grain yield was 15.5% under 360 ppm CO_2 concentration and the reduction is 9.7% with 550 ppm concentration in 2070.

Impact of elevated temperature and CO_2 scenarios in 2070 based on RCP 4.5 on crop productivity, water productivity and water footprints of groundnut (cv. Smriti).

Effect of climatic variables on global warming potential in chickpea

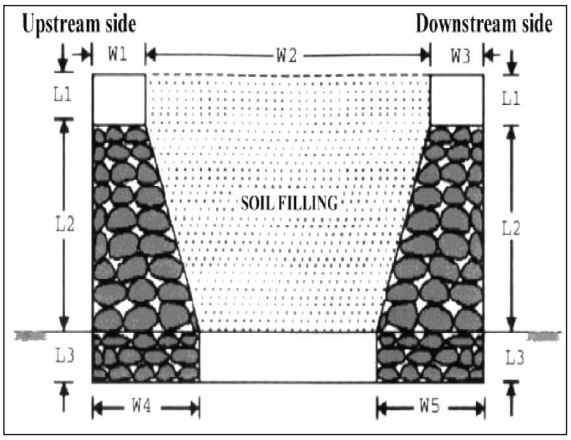
Temperature	2010	2070	Diff (%)
A. CO_2 Concentration : 370 ppm			
Crop duration (days)	122	115	-5.74
Grain yield (t ha^{-1})	1660	1440	-15.54
Crop evapo-transpiration (mm)	381	402	5.51
Water productivity in terms of crop evapo-transpiration (kg m^{-3})	0.44	0.36	-17.78
Water footprints (m^3 t^{-1})	2295.1	2791.6	21.63
B.CO_2 Concentration : 550 ppm			
Crop duration (days)	122	115	-5.74
Grain yield (t ha^{-1})	1750	1580	-9.71
Crop evapo-transpiration (mm)	381	402	5.51
Water productivity (in terms of ETc) (kg m^{-3})	0.46	0.39	-16.10
Water footprints (m^3 t^{-1})	2177.1	2544.3	16.86

Developments of suitable groundwater recharge structure and low cost water harvesting structure and standardizing methodology of multiple uses for enhancing water productivity (IIWM)

Location specific groundwater recharge techniques suitable for specific geo-hydrological conditions have been developed and tested for their performance in terms of recharge rate and area of influence. Dry stone masonry pond, single wall masonry structure and cement masonry structure were constructed at Kherad, Som , Karget and Shisvi villages of Udaipur district, Rajasthan. The overall storage capacity of water harvesting structures constructed at Shishvi and masonry check dam at Karget were 4235 and 3985 m^3, respectively. The average recharge rates were found to be 6.80 to 7.10 cm / day and volume of total recharge that can be carried out by constructing 2 m height of masonry check dam will be about 24500 m^3.

Further, in this study, a dry stone masonry type low cost rainwater harvesting structure for groundwater recharging was designed and developed by Udaipur centre. This structure is most suitable to harvest the rainwater up to catchment area of 50 ha and also for

augmenting the groundwater table of the wells located in the downstream area of the structure through continuous recharging.



Cross section of dry stone masonry pond

Low cost dry stone masonry structure constructed at Shishvi village

Masonry check dam at Karget

Masonry check dam at Shishvi

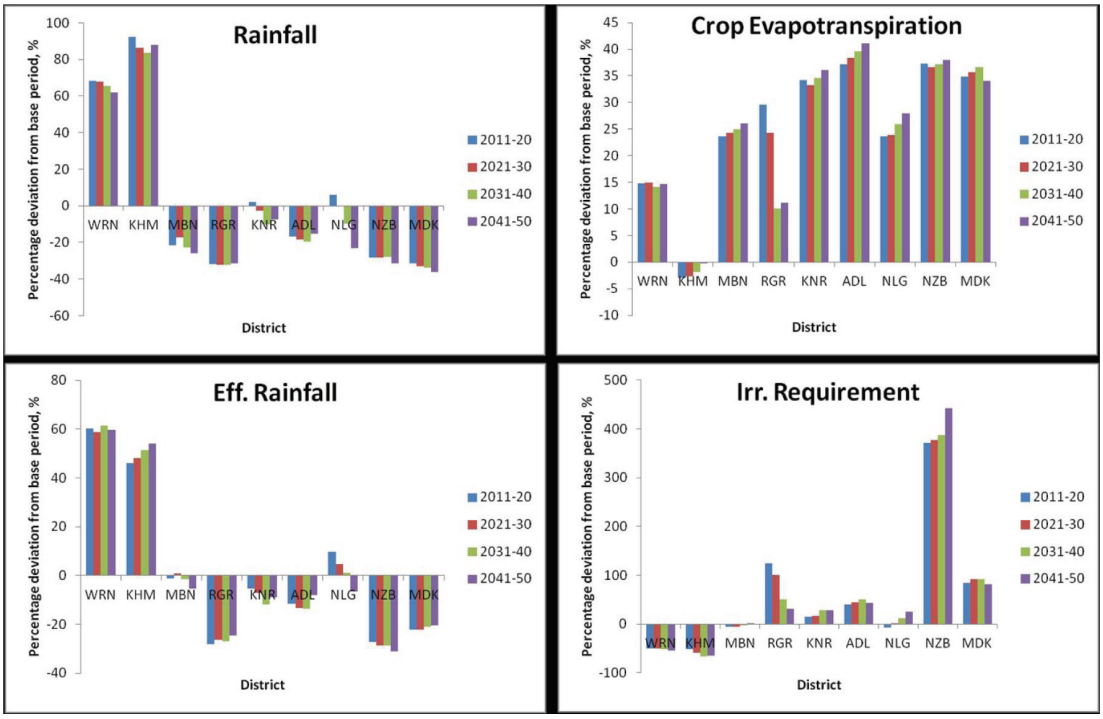
Masonry check dam at Som

Similarly, suitable water harvesting cum groundwater recharge structures were developed and evaluated at Gujarat and Tamilnadu. These structures also have appreciable water storage capacity.

Climate change impacts on crop water balance of maize (CRIDA)

The crop water balance for the two crops namely maize (*Zea mays L.*) and cotton (*Gossypium herbaceum)* have been estimated for nine districts of Telangana by using CROPWAT model using long term climate data of the period 2011-2050 generated from CCAFS-Marksim DSSAT Weather file generator. The climate series include a downscaled data from ECHam5 GCM Model for A1b Scenario. The analysis indicated that during the normal sowing window of maize, the rainfall decreased in the range of 20-40% in all the districts except in Warangal and Khammam districts which have shown an increasing trend from 60-90%. Similarly, the effective rainfall decreased in the range of 5-30% in seven districts while increasing trend is observed in Warangal and Khammam districts from 45-60% in four decades (2011-2050). The crop evapotranspiration increased in all

the districts in the range of 15-40% over four decades except in the district of Khammam with the slight decrease of 3%. The irrigation requirement increased from 25-125% over the base period in five districts (Rangareddy, Karimnagar, Adilabad, Nalgonda and Medak) and decreased in the range of 50-75% in two districts (Warangal and Khammam). However, in the case of Nizamabad, the irrigation requirement increased from 3 to 4 times over the base period in all the four decades.



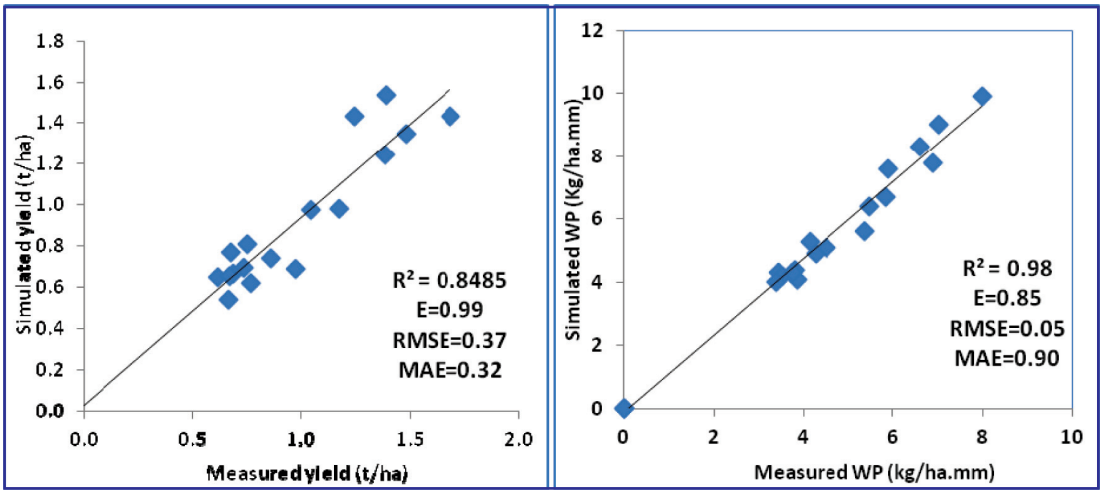
Climate change impacts on crop water balance during crop growth period of maize under normal sowing window for A1b Scenario for the period 2011-2050 over base period

Assessment of rainwater productivity of maize (*zea mays L.*) through Aquacrop model under different supplemental irrigation strategies in semi arid alfisols (CRIDA)

AquaCrop model was validated with the experimental data during 2014. With hybrid maize crop Monsanto, Dekalb 900 M.Gold).

The experimental datasets were used for validation of FAO AquaCrop model to simulate grain yield, above ground biomass and water productivity. The model predicted well the grain yield and biomass yield and water productivity under drought situations also. There was a good agreement between measured and simulated grain yield and water productivity with R^2 of 0.93 and 0.86 respectively. The model simulated grain yield and water

productivity with an efficiency of 0.99 and 0.85 respectively which are within the acceptable limits. It is observed that 50 mm supplemental irrigation along with mulching is the best adaptation strategy through farm ponds for climate resilience. It is followed by 40 mm, 30 mm and 20 mm.



AquaCrop model validation with performance indicators

Micro sprinkler irrigation in tomato to increase water productivity and to mitigate the high temperature stress in summer (IIHR)

Micro sprinkler irrigation was compared with drip and furrow irrigation to mitigate the effect of high temperature in summer tomato production. Micro-sprinkler was run for 10 minutes duration each at 12 noon, 1pm and 2pm. Significantly highest yield was recorded with drip fertigation (88.1t/ha). The yield under both drip irrigation and micro-sprinkler irrigation was significantly superior to furrow irrigation. There was a marginal difference in the water use efficiency between drip and sprinkler systems. The temperature dip due to micro-sprinkler irrigation is to the tune of 2.4°C, and the raise in relative humidity is upto 4.5%.

Effect of application of polymer on rainfed maize grown on sandy soil (CRIDA)

The application of polymers viz., *polyacrylamide and potassium acrylate (PAM)* at 25 kg/ha delayed the wilting of maize by 5-6 days during initial dry spell at early growth stage of maize. Application of PAM at 25 kg/ha maintained higher moisture retention in soil at different crop growth stages as compared to control, indicating that the polymer may enhance crop growth, yield and rain water use efficiency in short term dry spells, but may not be effective if the amount of rainfall received is significantly less with prolonged dry spells.

PAM untreated plot

PAM treated plot

Groundwater resource management to mitigate the impact of climate change in Punjab & Haryana (PAU & CSSRI)

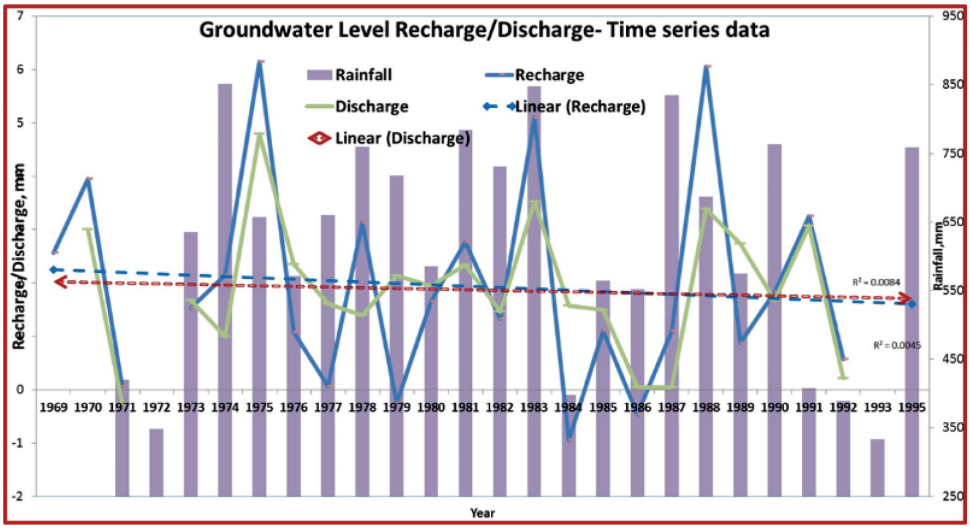
The focus of study is on estimation of crop water demand under changing climate, development of low cost structures as vertical drainage facility, innovative agronomic interventions for reducing groundwater withdrawal and to study the impact of land use changes and cropping pattern on natural recharge to groundwater resources. The future daily climate data was generated by using ClimGen model for CROPWAT computer program to estimate future crop water requirement.

The CROPWAT model was used to estimate evapo-transpiration, effective rainfall and net irrigation of rice–wheat and maize–wheat cropping systems under changing climate. The results indicate that evapo-transpiration of DSR would increase in mid and end of the century. In mid-century, increase in ET of DSR was found to be 12 mm in entire crop growing season as compared to the base period. However, in the end of the century, increase in ET was estimated to be about 70 mm as compared to the base period ET. Net irrigation requirement (NIR) does not follow the similar trend, and NIR for base period and end of the century was almost similar (258.7 and 252.0) despite of 70 mm difference in ET.

Performance of different cropping patterns has been evaluated in central Punjab for kharif season and saving of water to reduce stress on groundwater extraction has been determined through field experiments. The values of average water productivity and BC ratios of some of the alternate systems were high and these systems had good potential for adoption by the farmers. Direct seeded basmati-canola or transplanted basmati- canola have been suggested as good options to replace rice-wheat.

Influence of climate variability on groundwater (CRIDA)

Efforts were initiated to ascertain the groundwater variability, recharge and discharge on year to year basis and as a function of rainfall. Longterm data on groundwater fluctuations was collected from state groundwater department. Mandal level rainfall was collected from bureau of economics. Preliminary analysis of the data for Makhtal mandal of Mahabubnagar district, Telangana, showed increase in recharge and discharge of ground water with increase in rainfall indicating that there is no carry over storage of ground water from year to year.



Influence of rainfall on groundwater recharge and discharge

Enhancing nutrient and energy use efficiency and Carbon sequestration for climate change mitigation

Design and development of seed-cum-ferti drill with differential depth fertilizer application system (CIAE)

A five row seed cum fertilizer drill was developed to apply the phosphorous and potash at different depth to improve the fertilizer use efficiency. Application of fertilizers at root zone of crops result in higher fertilizer use efficiency. Different furrow openers for seeding and fertilizer application have been mounted in a seed drill and evaluated for seed placement at different depths. This seed cum fertilizer drill was tested in a field experiment with maize and

Tractor operated multi row seed-cum-ferti drill during field operation.

soybean as test crops. Placement of fertilizer at 20 cm below the surface in maize and soybean proved to be effective when compared to other depths. However, these results need to be verified. The estimates showed that the machine could save 5-10 percent fertilizer due to higher fertilizer use efficiency.

Design & development of zero-till drill with straw handling mechanism for sowing under heavy residue conditions (CIAE)

Prototype of machine was developed and its evaluation was done for paddy crop harvest. Modifications in the design of the transmission assembly and furrow opener assembly were done based on field evaluation.

Prototype

The furrow opener sub-assembly has been redesigned, to reduce the distance between the cutting point and seed-placement point to the minimum possible.

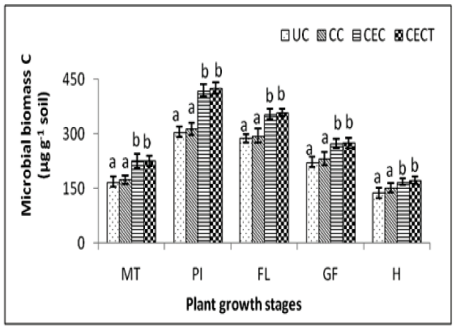
Energy use efficiency of conservation agricultural practices in Pigeonpea - castor systems (CRIDA)

Energy analysis was conducted for conservation agriculture practices and conventional agriculture in pigeonpea and castor systems. Different tillage systems significantly influenced the energy inputs whereas residue levels did not differ significantly. Total energy inputs averaged across castor and pigeonpea was 8.5, 7.5 and 5.9 GJ ha^{-1} in conventional tillage (CT), reduced tillage (RT) and zero tillage (ZT), respectively. CT recorded 30 and 12% higher energy input over zero and reduced tillage, respectively. The fossil fuel share in CT (34%) and RT (26%) was higher where as in zero tillage it was only 16% was due to land preparation and sowing. It was less as compared to other studies due to use of CRIDA precision planter for sowing and the advantage of this implement is sowing, fertilizer and pre-emergence application of herbicide is done simultaneously in a single operation.

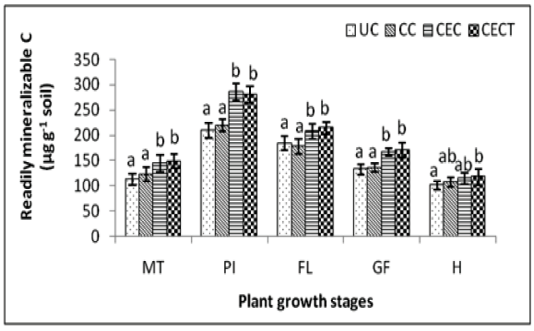
Effect of elevated carbon dioxide on rice cultivars and soil labile C pools and enzymes (CRRI)

Field studies were conducted to investigate the impact of elevated carbon dioxide (CO_2)

(550 and 700 µmol mol^{-1}) on different rice varieties viz. *Pooja, Swarna, Gayatri and Moti* in *Kharif* season 2014. The results of the study revealed that the grain yield was significantly higher under elevated CO_2 compared to that of the ambient CO_2 irrespective of the rice cultivars. The labile carbon pools including microbial biomass carbon (MBC) and readily mineralizable carbon (RMC) were found significantly higher both under two levels of elevated CO_2 (550 and 700 ppm) compared to that of the ambient CO_2. The MBC and RMC contents varied from 150-425 µg g^{-1} and 170-310 µg g^{-1} under different treatments in the study. The dehydrogenase and fluorescein diacetate (FDA) activity was also found significantly higher under both the levels of elevated CO_2 irrespective of the rice cultivars. The dehydrogenase and FDA hydrolytic activity varied in the range of 340-520 mg TPF g^{-1} day^{-1} and 3.7-7.6 µg fluorescein g^{-1} h^{-1}, respectively in different treatments.



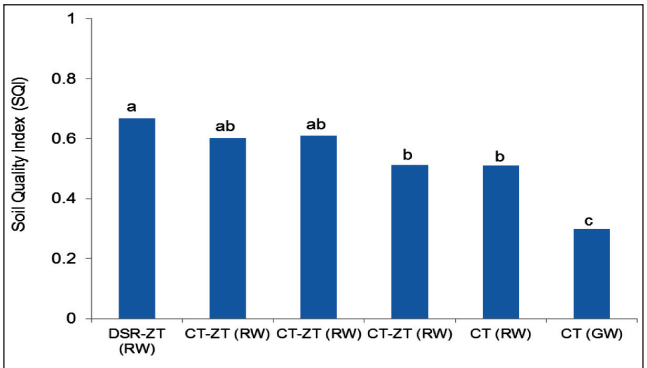
Microbial biomass carbon content under elevated CO_2



Readily mineralizable carbon content under elevated CO_2

Impact of tillage on carbon sequestration and soil quality (IARI)

The short-term effect of different tillage practices significantly influenced the depth-wise distribution of soil organic carbon (SOC) in alluvial soils under rice-wheat cropping system. The conventional tillage (CT) in rice followed by zero tillage (ZT) in succeeding wheat crop significantly increased the SOC as compared to that in conventionally tilled rice and wheat (CT-RW) cropping system. There was a stratification of SOC down the soil profile where zero-tillage was introduced. The rice-wheat system retained more SOC than the guar-wheat system. The build-up of SOC in CT-ZT combination in rice-wheat cropping system was truly reflected in overall



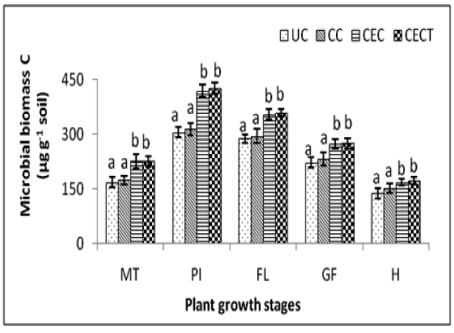
Effect of different tillage management on soil quality index (SQI) developed under principal component analysis (PCA) based framework.

(NB: The SQI data bar followed by different lower case letters are statistically significant according to Duncan's Multiple Range Test (DMRT) at P=0.05, DSR - Direct seeded rice, CT – Conventional tillage, ZT – Zero tillage, RW – Rice-wheat, GW – Guar-wheat)

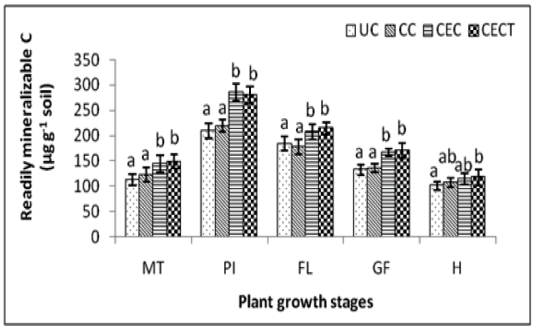
improvement of soil quality. The soil quality indices developed by encompassing eighteen soil physical, chemical and biological parameters were significantly improved due to introduction of ZT in wheat under rice-wheat system.

Effect of elevated carbon dioxide on rice cultivars and soil labile C pools and enzymes (CRRI)

Field studies were conducted to investigate the impact of elevated carbon dioxide (CO_2) (550 and 700 µmol mol^{-1}) on different rice varieties viz. *Pooja, Swarna, Gayatri and Moti* in *Kharif* season 2014. The results of the study revealed that the grain yield was significantly higher under elevated CO_2 compared to that of the ambient CO_2 irrespective of the rice cultivars. The labile carbon pools including microbial biomass carbon (MBC) and readily mineralizable carbon (RMC) were found significantly higher both under two levels of elevated CO_2 (550 and 700 ppm) compared to that of the ambient CO_2. The MBC and RMC contents varied from 150-425 µg g^{-1} and 170-310 µg g^{-1} under different treatments in the study. The dehydrogenase and fluorescein diacetate (FDA) activity was also found significantly higher under both the levels of elevated CO_2 irrespective of the rice cultivars. The dehydrogenase and FDA hydrolytic activity varied in the range of 340-520 mg TPF g^{-1} day^{-1} and 3.7-7.6 µg fluorescein g^{-1} h^{-1}, respectively in different treatments.



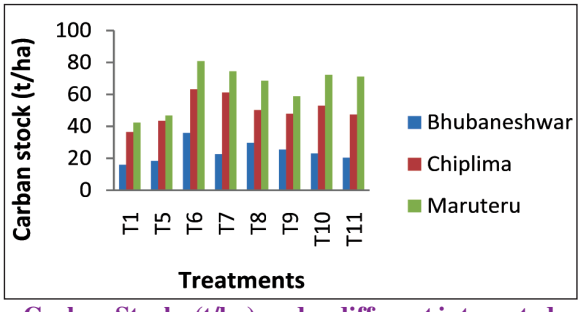
Microbial biomass carbon content under elevated CO_2



Readily mineralizable carbon content under elevated CO_2

Carbon stocks and carbon sequestration rate under different integrated nutrient management practices (IIFSR)

The carbon stocks and sequestration rate under different integrated nutrient management practices were computed under AICRP-IFS experiment at different centers viz., Bhubaneshwar, Chiplima and Maruteru. The highest carbon stocks of 35.85 t/ha, 63.18 t/ha and 80.79 t/ha



Carbon Stocks (t/ha) under different integrated nutrient management practices

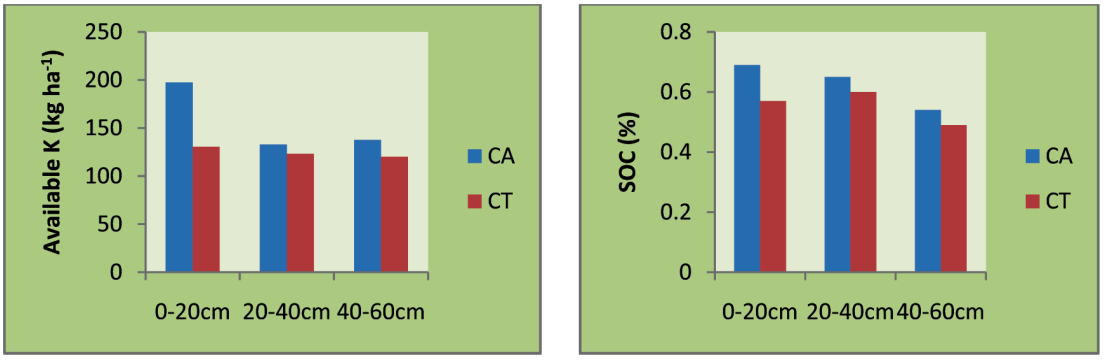
(NB: T1- Control; T5-Recommended dose of fertilizer; T6-50 % FYM; T7-25 % FYM; T8-50 % Crop Residue (CR); T9-25 % CR; T10- 50 % Green manure (GM); T11- 25 % GM)

were recorded at Bhubaneshwar, Chiplima and Maruteru, respectively under incorporation of 50 % FYM along with 50 % inorganic N application. Further, it was also found that the highest carbon sequestration rate of 835.64 kg/ha/yr, 938.99 kg/ha/yr and 1622.40 ka/ha/yr, respectively was recorded at Bhubaneshwar, Chiplima and Maruteru, respectively with incorporation of 50 % FYM along with 50 % inorganic N application.

Effect of conservation agriculture practices on productivity and nutrient use efficiency in maize-horsegram cropping sequence in rainfed Alfisols (CRIDA)

Conservation agriculture (CA) can play a major role in stabilizing production in rainfed regions by mitigating water and nutrient stress and also by improving nutrient use efficiency.

A field experiment was started since 2012 on sandy loam soil of Gunegal research farm of CRIDA to study the effect of CA practices and balanced fertilization on performance of maize-horsegram cropping sequence, and the impact of CA on soil properties. In 2014-15, plant population was very low due to drought. Further, due to severe water stress during grain development and grain filling stage, there was no economic yield. Soil organic carbon (SOC) was improved by practicing CA (0.69%) compared to conventional practices (CT) (0.57%). There was a buildup of available K at all the soil depths due to CA practices.



Effect of Conservation agriculture (CA) on soil organic carbon and available K

Surface residue application under minimum tillage as an adaptation strategy in rainfed alfisols (CRIDA)

Soils in the rainfed regions suffer due to deterioration of soil quality resulting in low yield of crops. Surface application of 4 levels of sorghum residues @ 0, 2, 4, 6 t ha^{-1} in combination with N (30 kg N ha^{-1} for cowpea and 60 kg N ha^{-1} for sorghum through urea) and uniform dose of 30 kg P_2O_5 ha^{-1} (through super phosphate) with minimum tillage., was conducted in sorghum-cowpea rotation. Significantly higher cowpea yield (538 kg ha^{-1}) was obtained with application of sorghum stover @ 6 t ha^{-1} followed by @

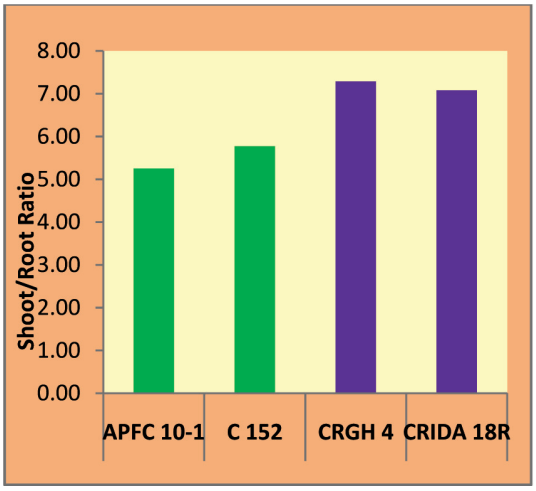
4t ha^{-1} (328 kg ha^{-1}) and 2 t ha^{-1} (296 kg ha^{-1}) compared to control (208.7 kg ha^{-1}). Soil compaction at 21 DAS and after harvest of the crop was significantly lower with application of sorghum residue @ 6 t ha^{-1} at all the depths measured (0-10 cm). Further, the residue treatment also significantly increased the water infiltration rate by 58% over control. Thus, the application of crop residue in combination with minimum tillage helped in reducing soil compaction and increasing water infiltration which in-turn can be effective adaptation mechanism towards climatic ill effects.

Mitigation of climate change by reducing Carbon Footprints (CF) through conservation agriculture in rainfed regions (CRIDA)

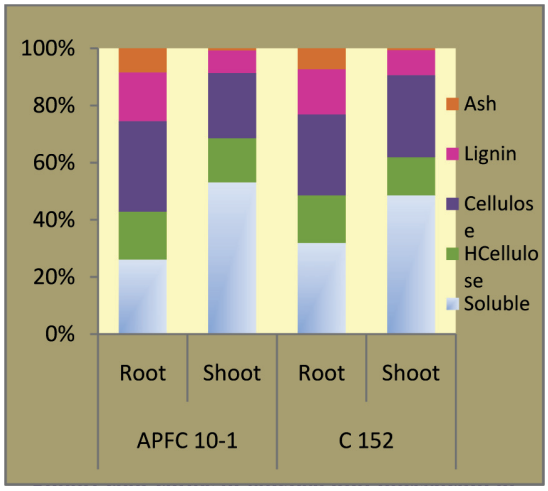
The carbon footprint of conservation agriculture and conventional tillage were estimated in pigeonpea and castor crops in rainfed Alfisol. Total carbon foot print (CF) from various practices like decomposition of crop residues, application of synthetic N fertilizers, field operations, and input (fertilizer, pesticides) production were computed. Emission factors were used to estimate the total CF. On an average, the contribution of direct N_2O emissions to total GHG emissions was 56 and 62% in castor and pigeonpea, respectively. The CF (considering GHG emissions from operation use and input use) was lower by 23 and 9% in zero tillage (ZT) and reduced tillage (RT) over conventional tillage (CT). Yield scaled and spatial CF was influenced by tillage and residue treatments. Further, castor grown on pigeon pea residue recorded 20 percent higher GHG emissions over pigeon pea grown on castor residues. Fuel consumption in ZT was reduced by 58 and 81 percent as compared to CT in pigeon pea and castor, respectively. The results indicate that, there is a scope to reduce the CF by reducing one tillage operation (RT) with harvesting at 10 cm height with minimal impact on the crop yields.

Role of plant roots in soil C sequestration

The study was initiated in 2011 to understand the role of plant roots in sequestering carbon in soil. In kharif 2014, two varieties each of cowpea (C 152 and APFC 10-1) and horse gram (CRIDA 18 R and CRHG 4) were grown in 100 L plastic containers filled with ~120 kg red sandy loam soil. Root systems of the plants were extracted by washing away the soil in the containers with a jet of water. Roots were extracted at two stages, maximum biomass stage (late flowering) and crop maturity. After washing away the soil, root and shoot portions were separated, dried and weighed. Shoot:root ratios at maximum biomass stage were higher for horse gram compared to cowpea. Roots of both the varieties of each of the crops had lower soluble fraction and higher fibre fraction, especially recalcitrant fraction - lignin, compared to shoots, suggesting that roots may decompose more slowly in soil than shoots.



Shoot: root ratios of cowpea and horsegram at maximum biomass stage



Shoot: root ratios of cowpea and horsegram at maximum biomass stage

Conservation horticultural practices for improving soil properties and enhancing carbon sequestration potential in mango based cropping system (IIHR)

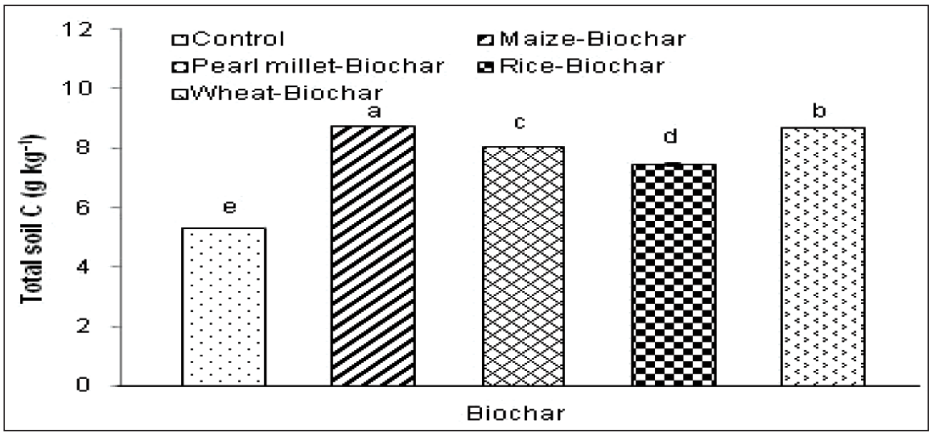
The effects of conservation horticultural practices on soil physical, chemical, biological and biochemical properties in mango orchards under four distinct management situations in semiarid tropical regions on Alfisols were assessed during the current year. Effect of conservation practices like minimum tillage, inter crops and residue management on soil bulk density (BD) was conspicuous and mainly confined to the surface part and plough layer. Surface soil (0-5 cm) generally had lower BD than plough layer. Both the crops and conservation practices had significant influence on the post-harvest soil profile moisture storage. Vegetable system exhausted the soil water more than fruit orchards. Conservation practices like inter and cover crops with zero tillage has conserved soil moisture more than other orchard plots with clean cultivation practices and weed infestation. The effect of conservation practices was more pronounced in macro aggregates than micro aggregates. All plots with conservation practices had higher dry macro aggregates and water stable macro aggregates than intensive cultivation plots. Conservation practices in mango orchards significantly altered some of the basic soil chemical properties like pH, exchangeable bases and exchangeable nutrient cautions. The soil available nutrients status changed significantly under different treatments.

Soil organic carbon fractions in different conservation plots

Soil properties	CCVF	CCIM	WCIM	CHPM	CHSP	CHPC	LSD (0.05)
Loss on ignition (LOI), g kg^{-1}	9.86	10.98	11.03	11.85	11.27	12.34	0.96
Organic C(OC).g kg^{-1}	5.16	5.78	6.02	6.32	5.98	6.64	0.51
Active C(AC), mg kg^{-1}	18.06	20.23	29.07	37.7	26.82	35.24	2.37

CCVF: Clean cultivation vegetable field; CCIM: Clean cultivation intensive management; WCIM: Weed cover intensive management; CHPM: Conservation Horticulture practice (*Mucuna*); CHSP : Conservation Horticultural practice (Sweet Potato) ; CHPC : Conservation Horticultural practice (Cowpea)

Application of biochar on an average increased Total Soil Carbon (TSC) in the range of 41 to 65%. The TSC was highest in maize stover and wheat straw biochar treated soils, while it was observed lowest in the case of rice straw biochar treatment. Total C mineralization from maize stover biochar was marginally lower than that from wheat straw biochar and thus the differences in TSC were found to be non-significant. The low C content and high C mineralization from rice straw biochar were the prime reasons behind less enrichment of soil C in this treatment. The TSC in pearl millet stalk biochar treated soil was in between the above two biochar materials.



Effect of biochar from different sources on total soil carbon at the end of one year (Bars with different lower case letters are significant according to Duncan's multiple range test at P=0.05)

Assessment of biochar on productivity, nutrient use efficiency and C sequestration potential of maize based cropping system in north-east region (ICAR-NEH)

Application of biochar @ 5.0 t/ha significantly improved the yield attributes and yield of maize and French bean. Higher soil microbial biomass carbon (SMBC), dehydrogenase enzyme activity (DHA) and soil organic carbon (SOC) was observed with the application of biochar @ 5.0 t/ha and with 75% RDF + 4 t/ha FYM while exchangeable aluminium and exchangeable acidity were reduced.

Maize crop response to different treatments

Biochar application for improving moisture retention & nutrient availability in rainfed alfisols (CRIDA)

During the fourth year of experimentation, biochar residual effect on soil quality and crop performance was assessed with one time application of different biochar (maize, castor, cotton and pigeon pea stalk biochar) at different rates to maize (DHM 117) in rainfed alfisols. Residual maize stalk biochar @ 4 t/ha in soil along with RDF and FYM resulted in higher soil available N (175.6 kg/ha), phosphorus (22.5 kg/ha), potassium (328.0 kg/ha) and organic carbon content (15.1 g/kg). Higher soil available water (8.8 %) (v/v) was observed with residual maize stalk biochar @ 4 t/ha with RDF and FYM

compared to control (1.2%). The increase in soil available water could be attributed to higher organic C content in biochar amended soil and improved soil structure.

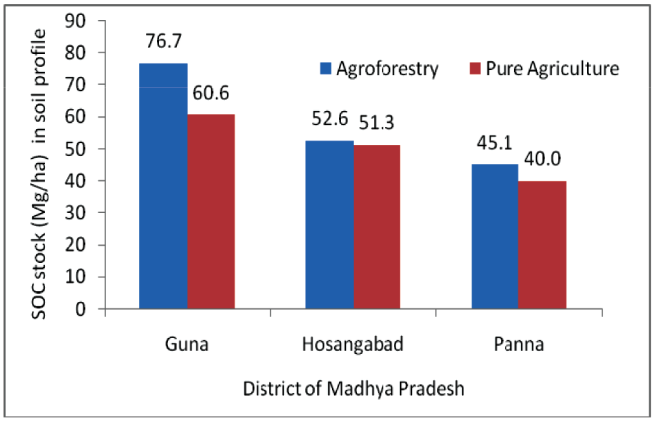
Maize (DHM 117) crop under different residual biochar amendments in Alfisol.

Assessment of Carbon sequestration potential of agroforestry systems (CAFRI)

Mapping of agroforestry area through GIS and Remote Sensing:

Land use and land cover analysis of the selected districts in Madhya Pradesh (Guna, Panna & Hoshangabad) and Rajasthan (Bikaner, Dausa & Pali) using RS2/ LISS-3 data has been done and agroforestry area was estimated. Area under agroforestry in the selected agro-climatic zones was estimated to be 0.80 M ha (11.91%), 1.30 M ha (7.87%), 0.19 M ha (5.09%) and 0.042 (2.39%), respectively.

The major tree species existing on farmer's field in three districts of Rajasthan are *Prosopis cineraria, Acacia tortilis, Prosopis juliflora, Azadirachta indica, Dalbergia sissoo* and *Ziziphus mauritiana.* Similarly in four districts of Madhya Pradesh, the major trees existing on farmer's field are *Eucalyptus tereticornis, Acacia nilotica, Leucaena leucocephala, Azadirachta indica* and *Tectona grandis*



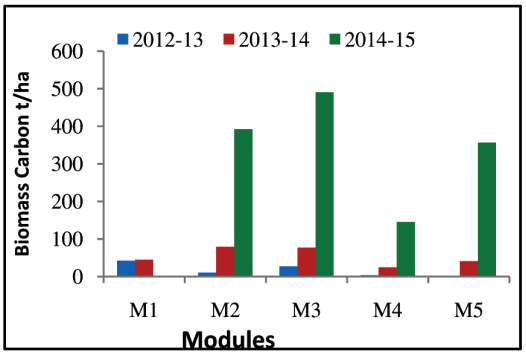
SOC stock (Mg/ha) in soil profile (0-90cm) of Madhya Pradesh

The biomass, biomass carbon, total carbon and net carbon sequestered in existing agroforestry system at district level in Karnataka, Rajasthan, and Madhya Pradesh was estimated by using CO_2FIX

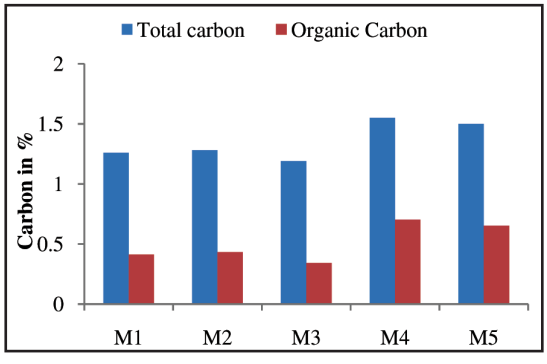
model and extrapolated for next 30-years. In case of Pali, Dausa and Bikaner districts of Rajasthan, the total carbon stock available in baseline varied from 9.0 to 24.45 t C ha^{-1} and it expected that over 30-years period the total carbon stock in agroforestry in these districts would be 13.32 to 35.39 t C ha^{-1}. Net carbon sequestered over the simulated period of 30-years would be 4.32 to 10.94 t C ha^{-1}**.** The tree biomass, soil carbon and total carbon available in existing agroforestry system in different districts of Madhya Pradesh is 3.57 to 7.39 DM ha^{-1}, 12.04 to 23.38 t C ha^{-1} and 16.10 to 27.61 t C ha^{-1}, respectively and its corresponding values over the simulated period of 30-years would be 7.75 to 11.99 t DM ha^{-1}, 12.74 to 24.80 t C ha^{-1} and 20.83 to 32.39 t C ha^{-1}, respectively.

Carbon sequestration through sustainable management of ravines (RVSKVV)

Management of ravines through a suitable module has a great role in climate resilience. In 8 ha land, half mount terracing was done with the help of earth moving machinery. Contour survey of selected area was also done and conservation structures were constructed. Two gabion check dams with mattress and reverse filter, one masonry structure and several earthen dams were established in the gullies and their effects on gully development were measured**.** The bio-mass carbon of different modules was estimated for the year 2012-13, 2013-14 and 2014-15. During the year 2014-15, the bio-mass carbon was highest in horti-pastoral module (M_3) followed by agri-horti module (M_2), silvi-pastoral module (M_5), silvi-medicinal module (M_4) and diversified cropping system (M_1). The change in biomass C was in the order of: 89 per cent in module M_5 > 85 per cent in M_3> 84 per cent in M_4 > 80 per cent in M_2. The highest total C and total organic C was recorded in silvi-medicinal module that is 1.55 % and 0.73 %, respectively, followed by silvi-pastoral module, agri-horti module, diversified cropping system and horti-pastoral module.



Biomass carbon in different modules of ravine Management



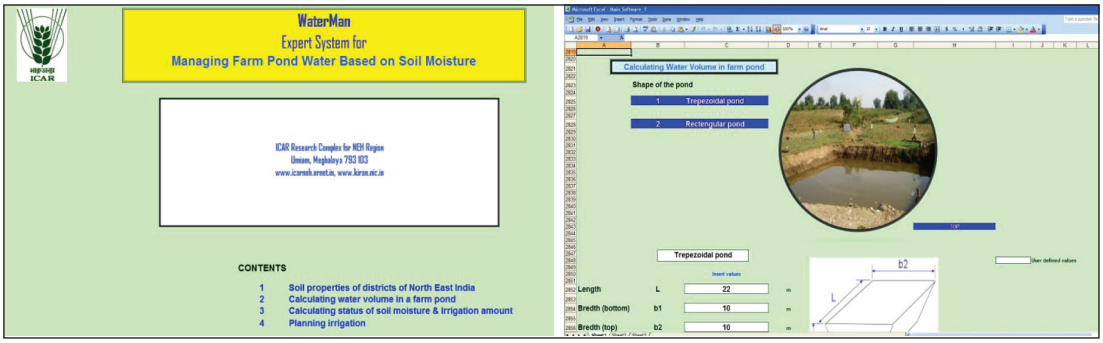
Total and organic carbon in different modules

Greening of the ravines

Resource conservation technologies for adaptation in North East Region (ICAR-NEH)

Assessment of climate resilient soil and water management (SWM) practices was focussed and a land use modal was developed on topo-sequence basis for in situ, SWC and carbon sequestration.

In order to make effective decision making in water management, a computer based EXPERT SYTEM on FARM WATER MANAGEMENT (WaterMan) was developed. The system has been loaded with soil information data base of every district of the eight North Eastern states (source: Harmonized World Soil database, FAO). Calculation of available soil moisture has been done based on pedo-transfer functions proposed by KE Saxton (SPAW model). Although, the system has been primarily designed for the subject matter specialists of the KVKs, but is also useful to farmers with some computer awareness.

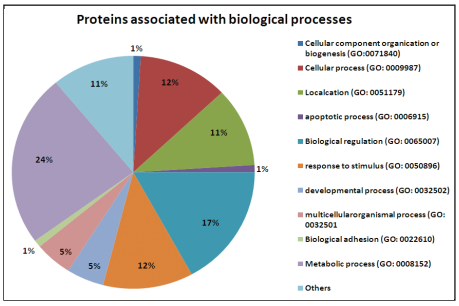


To promote resource conservation, crop diversification and enhancing cropping intensity in sloppy land (30 - 40% slope), a land use model has been tested for four years involving natural forest, fodder crops, cereals, pulses and oilseed crops after incorporation of components which contributes to resilience to climate. Soil organic carbon (% SOC) was found maximum in fodder based system at both 0-15 cm and 15-30 cm depths (2.18 % and 2.16 %, respectively) and SOC stock was found maximum in fodder based system at 15-30 cm depth (39.85 t/ha). Soil loss was maximum in Farmers' practice (along the slope, residue removal) 30.6 - 42.5 t/ha and minimum in fodder crop based system (1.218 - 4.34 t/ha) whereas soil loss in cover crop ranged from 16.9 – 21.2 t/ha, in intercrop ranges from 14.9 – 23.7 t/ha and in sole maize ranged from 10.3 – 22.0 t/ha.

4.6 Impact and Adaptation Strategies in Livestock and Poultry

One of the key impacts of change in climate is on livestock and also this sector contributes to the same. Research on livestock covering cattle, buffalo, sheep, goat, pig and poultry production systems is an important activity under NICRA. The major focus was on understanding the impact of climatic factors on production and reproduction behavior, understanding unique traits in indigenous cattle and identification of cost effective adaptation strategies. The salient findings are summarized below:

Heat Stress response in Large Ruminants (NDRI)



Identification of differentially expressed proteins in Sahiwal cows during summer season: Expression of serum proteins involved in biological processes vary with climatic conditions of a season and also breed of animal. The profile of the serum proteins in Sahiwal cows during summer (42 ± 0.6°C, RH 37.70 ± 2.4 %) season was performed by proteomics approaches following SDS-PAGE and mass spectrometry. A total of 140 serum proteins identified which are by far the largest number being reported for the first time.

Expression of HSP 27, 90 and 105 genes in peripheral blood mononuclear cells (PBMC) during thermal **Stress in Tharparkar and Karan Fries cattle:**

Effect of thermal stress on expression of HSP 27, 90 and 105 genes in Tharparkar and Karan Fries calves was evaluated. For HSP27, a total of 8 nucleotide sequence variations at positions: G225A, 2297insGTGGGGGA, C2298G, G2313C, C2331T, 2332delTC, T2335C, and T2352C was observed in buffaloes as compared to *Bos taurus*. For HSP90, a variations at 32 positions in comparison to the reference sequence of *Bos taurus* was observed. The expression of HSP 27, 90 and 105 genes in PBMC of Tharparkar and Karan Fries calves indicated that the expression of these genes were significantly higher in Karan Fries than Tharparkar calves. The alterations in physiological, haematological and hormonal responses were also significantly different between the two breeds indicating that Karan Fries calves were more sensitive to thermal stress.

The expression levels of different families of Hsp's (*in vitro*) in periparpurients Karan Fries and Sahiwal cows showed higher expression in Karan Fries compared to Sahiwal at higher temperature (42°C) than control temperature (37°C). Thus expression of HSP genes indicated that better adaptability of Tharparkar cattle compared to Karan Fries.

Zinc supplementation helped in lowering down the mRNA expression of HSP90á by about 2 to 3 times at a higher temperature (42°C). Zinc treatment also decreased the concentration of SOD that was otherwise increased while exposing the PBMC to 42°C

throughout the transition period in both the breeds. The concentration of catalyse was more on the day of calving at all the levels of exposure in both the breeds. The Zinc supplementation helped in reducing the stress levels in both the breeds of cattle.

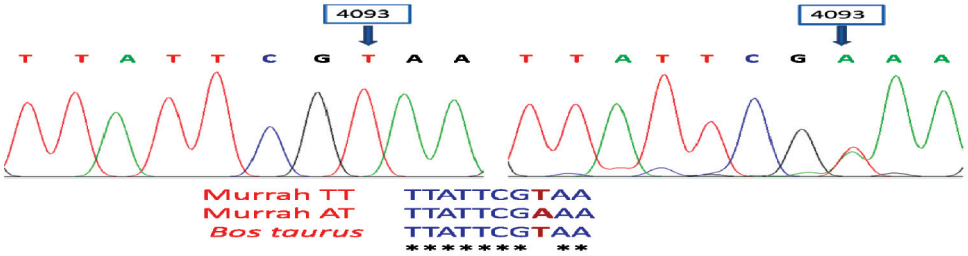
Molecular characterization and SNP identification of heat shock protein 90 gene in Murrah buffalo:

SNP identification of HSP27 and HSP90 gene in Murrah buffalo was carried out. Single nucleotide polymorphism (SNP) at position 4093(T/A) of HSP90AB1 gene with genotypes TT and AT having genotype frequencies of 0.15 and 0.85 respectively and gene frequencies of T and A as 0.57 and 0.43 respectively was found to have significant association with Rectal Temperature (RT). Statistical analysis showed significant association of parity, THI and SNP (eg.4093 T>A) with rectal temperature.

For HSP27, ClustalW revealed a total of 8 nucleotide sequence variations at positions: G225A, 2297insGTGGGGGA, C2298G, G2313C, C2331T, 2332delTC, T2335C, and T2352C as compared to *Bos taurus* (Ref. Seq. 000182.1). For HSP90, Clustal W analysis of nucleotide sequence revealed variations at 32 positions in comparison to the reference sequence of *Bos taurus* (NCBI–Gene Bank Accession No: AC_000180.1).

Identification of SNPs of ATP1A1 and HSP90AB1 Gene in Cattles revealed that for ATP1A1 a total of six SNPs (T27008243C, A27008223G, T27008097A, C27008016T, G27008015A and C27007790A) were found in all studied breeds. All six SNPs were observed in Sahiwal and Karan Fries cows whereas SNP T27008243C was not observed in Jersey crossbred cattle. While for HSP90AB1, a total of six point variations (T17871421C, C17871485del, C17872061T, T17872112C T17872148G and A17872199C) were observed in the present study.

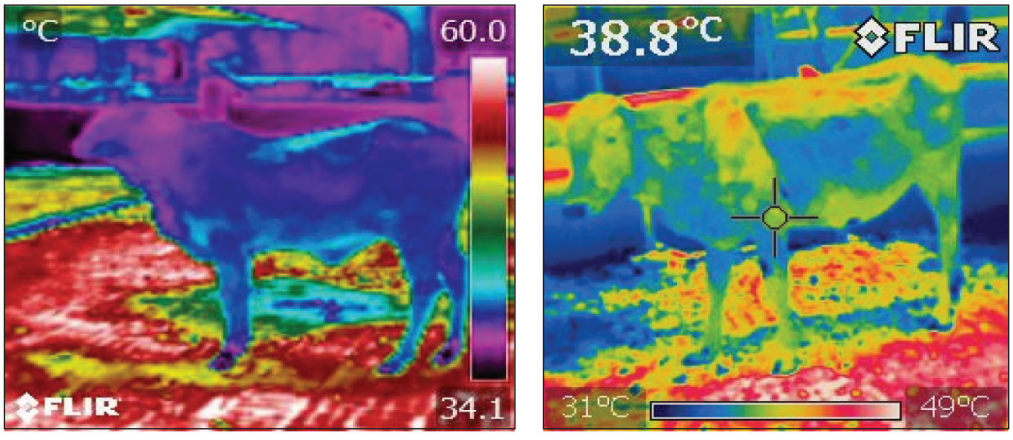
The TT genotype animals showed thermotolerance characteristics by maintaining lower rectal temperature during heat stress conditions. The THI observed during the period of study (49.7- 86.44) strongly supported that the animals were suffering from the heat stress. The identified SNP may be used as marker for selection of animals for thermo tolerance.



Chromatogram and Clustal W alignment showing variation at position 4093 (T>A) of HSP90AB1 gene in Murrah buffalo

Expression of Melanocortin-receptor (MC1R) & Physiological Adaptation to Thermal Stress in Cattle: Expression of skin color related genes (MC1R and PMEL) during thermal stress and their correlation with the morphological, physiological, haematological and biochemical changes as an adaptive mechanism in Tharparkar and Karan Fries heifer cattle showed that genes responsible for skin pigmentation (MC1R and PMEL) were found to be highly ($P<0.01$) expressed during winter than summer season. The magnitude of expression was significantly ($P<0.01$) higher in Tharparkar than Karan Fries especially during winter season. Expression of these genes showed negative correlation with physiological responses and heat stress and positive correlation with metabolic hormones.

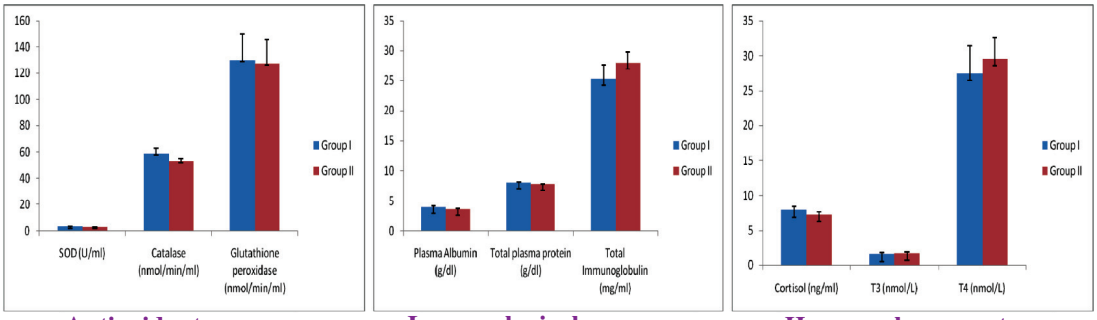
Insight into temperature adaptations of Tharparkar and Karan Fries cattle through thermal imaging during summer season: Thermal imaging allows the visualization of fixed or transient changes in the long-wave radiative energy emanating from an object, in essence, allowing for the estimation of surface temperature. Infrared thermography of Tharparkar and Karan Fries showed increase in body surface temperature with increase in ambient temperature during summer season in both the breeds. When ambient temperature was the highest, Karan Fries has higher surface temperature as compared to Tharparkar at dorsal, ventral, rump, head, ear and lower extremity of legs. Ear and lower legs act as thermal windows and these are the important thermoregulatory regions to maintain body temperature. Tharparkar which is lighter-colored and shiny hair coat reflected a greater proportion of incident solar radiation thereby maintain its body temperature than Karan Fries which is dark-colored and wooly hair coat absorbing heat and unable to maintain its body temperature. Hair coat of animals plays a critical role in heat and moisture transfer from the skin surface to the surrounding environment and in control of body temperature. Tharparkar seems to be a better adaptable breed to thermal stress than Karan Fries.



Tharparkar Karan Fries

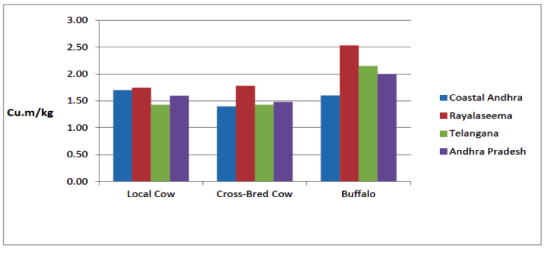
Thermal imaging of Tharparkar and Karan Fries cattle during summer season

Supplementation of vitamin C and amelioration of heat stress: Studies on primiparous Murrah buffaloes in their late stage of gestation with supplemented ascorbic acid @ 10 g/ animals/day from day 45 prepartum to the day of calving indicated that supplementation of vitamin C tend to shift the change in immune status (Lymphocyte proliferation index (LPI), neutrophil phagocytic activity (PA) and total Ig), biochemical parameters (TAS, TBARS, albumin and total protein), hormones (cortisol, T3 and T4) and physiological responses towards normalcy.



Antioxidant enzymes **Immunological enzymes** **Hormonal parameters**

Effect of vitamin C supplementation on hormonal, immunological and antioxidant enzymes in buffaloes



Average Water Footprint of Milk Production in Andhra Pradesh

Water foot prints of milk production: The results of the studies showed that WFP across breeds in Andhra Pradesh (rainfed cropping system) varied form 1600m^3/kg to 1990m^3/kg and that in Punjab (irrigated cropping systems) from 616m^3/kg to 774m^3/kg.

Identifying unique climate resilient traits in Ongole breed of cattle (CRIDA)

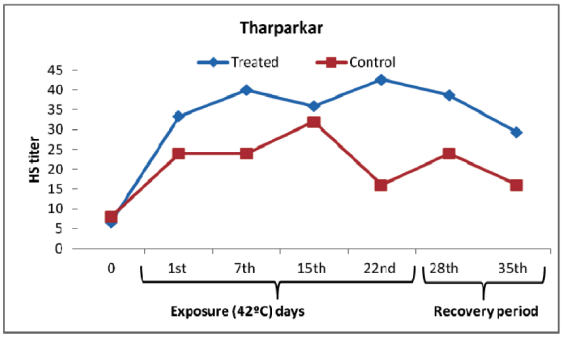
Heat stress imposed by exposing to ambient temperatures of 38-40°C resulted in induction of significant production of ROS, antioxidative enzymes [superoxide dismutase (SOD), catalase (CAT] and lipid peroxidase) activity in Ongole cattle. Within the first 12h after removal of the heat stress, the changes in the above parameters induced by heat stress gradually approached to pre-heat stress exposure levels. The results suggest that acute exposure to high ambient temperatures would depress the activity of the mitochondrial respiratory chain. This leads to over-production of ROS, which ultimately results in lipid peroxidation and oxidative stress and when the high temperature was removed, the production of ROS and oxidative injury gradually approached to the levels observed before exposing to heat stress, in a time-dependent manner.

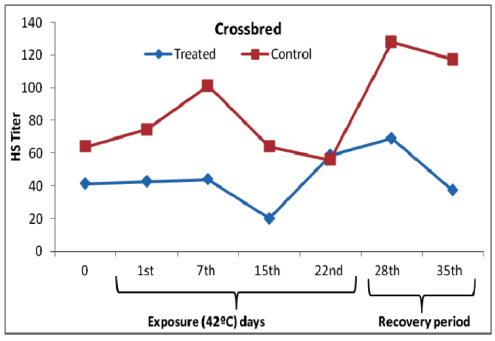
Antioxidant levels in Ongole cattle exposed to heat stress

Enzymes	Control	Exposed to heat stress for 4 hrs	12h after exposure to heat stress
SOD (102 U/L)	9.80 ± 1.18	14.60 ± 0.85	9.98 ± 1.21
Catalase (kU/l)	24.30 ± 2.58	40.92 ± 3.24	25.46 ± 1.82
Lipid peroxidase (µM)(TBARS)	0.96 ± 0.06	1.07 ± 0.09	0.97 ± 0.13

Factors responsible for resistance/susceptibility of native breeds of livestock to diseases in relation to climate change (IVRI)

Heat stress and humoral immune response: Antibody response to inactivated hemorrhagic septicaemia (HS) vaccine was better in Tharparkar than crossbred animals exposed to heat stress at 42^{0}C for 6 h daily for 22 days; probably this breed is well equipped to tackle heat stress as compared to crossbred animals. Further, antibody titre in treated Tharparkar was higher than control Tharparkar cattle.





Expression of innate immunity factors in crossbred and Tharparkar cattle: Differential expression of Cytokines (IL-1, IL-12, IL-1â, IFN-ã) and TLR-2 was studied in crossbred and Tharparkar cattle in different seasons of the year viz. winter, THI (67.01), hot dry (THI 91.85) and hot humid (THI 84.42). Expression of TLR-2, IL-1, IL-1â, IL-2, IL-12 and IFN-ã was relatively higher in crossbred cattle than Tharparkar indicating that crossbred cattle are under higher immune stress at same THI than the Tharparkar cattle.

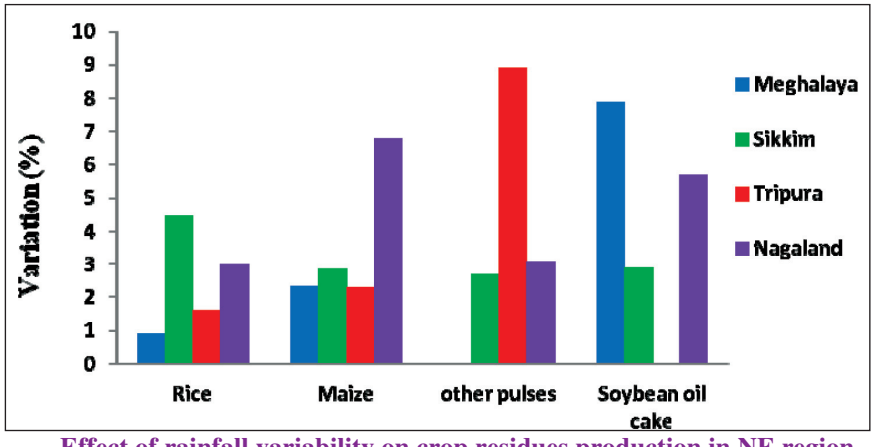
Impact of climate change on important vector borne and zoonotic diseases and vectors: Theileria was found most common blood protozoan in both summer and winter seasons among all agro-climatic zones expect Western Himalayan region. Prevalence of gastro-intestinal parasitism especially Trematode infections viz. *F. gigantica, P. epiclitum, F. elongatus, G. explanatum* and *S. spindale* in *L. auricularia, L. luteola, I. exustus and*

G. convexiusculus in cattle were recorded in different seasons of the year with a prevalence of 0.9-7.0% for the different parasitic species. Further, studies on prevalence of vector and intermediate hosts like sanils in different agro-climatic conditions indicated high numbers of snails during rainy season, followed by post-rains. In summer, snail density fell to insignificant ($p>0.05$) levels. This has a direct correlation with transmission of trematodes infection in domestic animals. Trematode infection in *L. auricularia* showed positive correlation with temperature. Higher temperature (25-320C) is a positive factor for development of intra-molluscan stages of the parasite and for higher cercarial shedding in seasons other than winter. *Fasciola gigantica* infection was recorded maximum during post monsoon season and winter season in *L. auricularia* (Intermediate host). In general amphistomes infection was found less during winter season due to aestivation habit of the snails (intermediate host). Among the ticks, *Rhipicephalus* (*Boophilus*) sp. was the most dominant tick genera recorded under study. *Hyalomma* sp. was found dominant in western dry region.

Climate variation and availability of field resources (NIANP)

The effect of climate variability on animal feed resources availability in 13 states including NE region covering Meghalaya, Sikkim, Tripura and Nagaland was analyzed using SAS time series forecasting system and auto regressive integrated moving average models.

Overall, among the major livestock feed resources, rice straw and sugarcane tops were impacted relatively less across different states, as the acreage under irrigation is relatively more for these crops. Some of the oil cakes were affected more by rainfall variability, as the proportion of irrigated area under these crops is limited and they are grown on marginal soils under rainfed conditions Among various studied states, the impact of climate variability is low on crop residues production in states like Punjab and Haryana, due to the maximum coverage of cropped area under assured irrigation. In a majority of the states, the extent of reduction in residues production varied from about 1.4 % in case of rice, 8% in case of other pulses, and 12 % for minor millets.



Effect of rainfall variability on crop residues production in NE region

Identification of the unique traits in indigenous pigs and poultry which make them resilient to climate change and development of database: (ICAR-NEH)

The salient unique traits of indigenous pigs were identified related to climatic variability like body shape and size, top line- slight concave to straight, pot bellied, skin: thin, loose and folded, bristles: long and coarse, early sexual maturity, high prolificacy, high disease tolerance as compared to exotic breed of pig. In Khasi local, the narrow, short face with concave snout, small and erect ears and Ghungroo with broad and flattened face, short and curved snout having large, pendulous and heart shaped ear which are more helpful in heat dissipation makes them more climate resilient as compared to exotic breeds. Another unique trait was bristles which are unique in physical, mechanical and chemical properties as compared to other livestock species. Very hard flexible coarse fibres with tensile strength 4-5 times higher as compared other animal fibres are also helpful in adverse climatic conditions with special mechanical property as compared to the exotic pigs which provide protection against extreme cold in this region. Similarly, Pot bellied condition may be one of the distinguish features for dissipation of heat during high temperature.

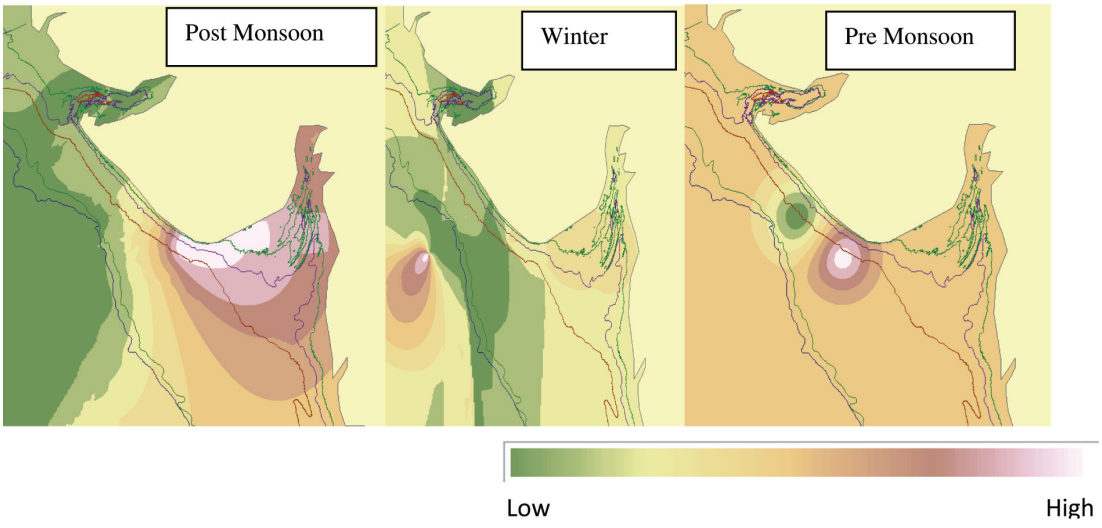
Climate resilient deep litter housing model for pigs: Designed and developed innovative low-cost pigpen using locally available resources used which are suitable for high rainfall and mid/high altitude region. Low temperature in conventional concrete pen causes stress and energy loss to the pigs during winter season, in contrast, saw dust-floor provided warm and comfortable environment to pigs. In rainy season, the conventional pigpen has always wet floor and higher THI as compared to the innovative developed pen leading to high growth rate and less diseases.

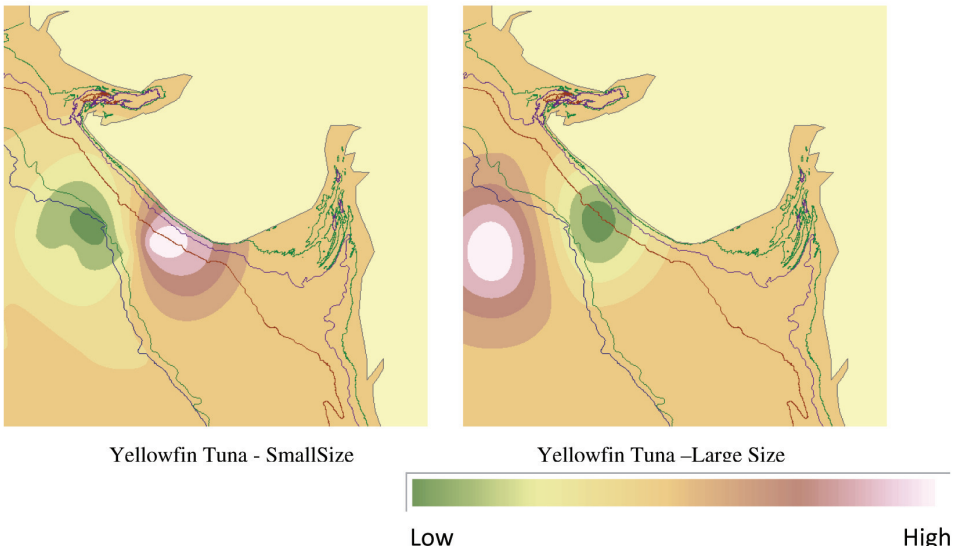
Evaluation of adaptability in poultry under variable climatic conditions: The study site was conducted in three sites to represent 3 distinct topographical locations with Menchuka (high hill and altitude range: 2000-4000 m-msl) comes under Temperate to Alpine Zone, Basar (mid-hills and altitude range: 600-700 m-msl) comes under subtropical- hill zone and Likabali (foot hill and altitude range: 200-300 m-msl) that comes under tropical agro-climate zone in Arunachal Pradesh. The yearly average temperature range of the three locations are Likabali: 5.0oC to 39.0oC; Basar: 2.0oC-36.0oC; and Manchukha: -0.5oC to 24.0oC. The effect of cold and hot weather on disease incidence, mortality and egg production of the poultry breed in three different conditions are closely evaluated. Also the various strategies adopted by indigenous farmers in the event of extreme weather such as excessive cold and hot have been collected and recorded for validation. Growth in body weight of Vanaraja is lowest in the foot hill of Likabali followed by Menchuka. The lesser growth rate in Menchuka may be attributed due to heat lost to keep the normal body temperature as, even during the hot season, night temperature falls to 11-16oC. Basar area had better growth than other two study sites due to its favourable moderate temperature. It was found that during cold season, overall gain in body weight was lowest in Menchuka followed by Basar, while Likabali exhibit highest growth. The probable reason may be due to heat loss in the cold places to maintain their body temperature. Also the mortality during the cold period is found to be highest in Menchuka, while Basar and Likabali had no significant mortality.

4.7 Impact and Adaptation Strategies in Fisheries

Fisheries research under NICRA covered marine, inland, estuarine ecosystems and brackish water aquaculture. The major focus was on understanding the impact of climatic factors on spawning behaviour and identify adaptation strategies to high temperature and other weather driven events like flooding. The salient findings are summarized below:

Seasonal distribution pattern of catch of Katsuwonus pelamis and Thunnus albacares in multiday Gillnetters off Gujarat : (CMFRI)

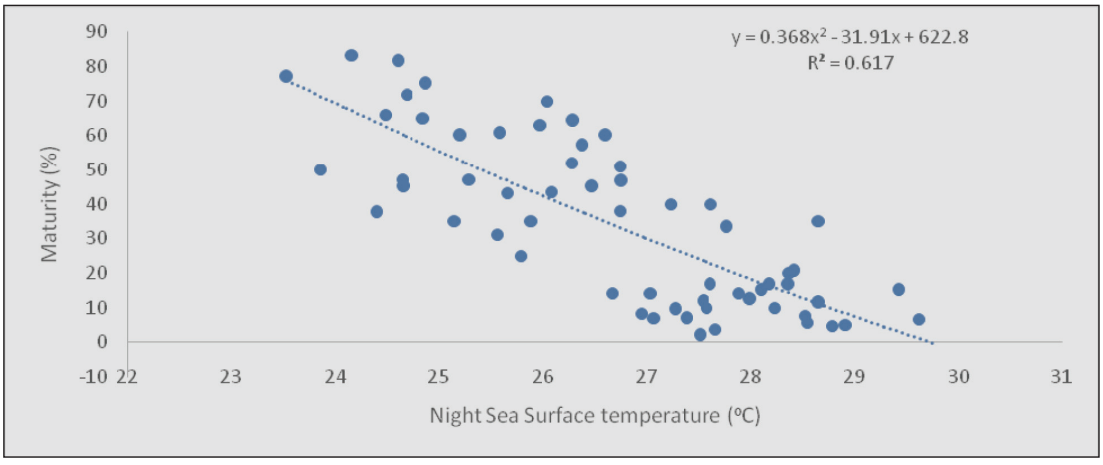




The results of Season-wise cum size-wise distribution pattern of Skipjack tuna studies indicates that the abundance is more in the off shores areas (100 m zone) during the

winter months (November, December and January), where as it moves towards the inshore areas (30-50 m zone) during pre-monsoon (March, April and May) and post-monsoon (September and October) season. Both small size and large sized tuna showed migration to the deeper waters during winter season. Differential distribution pattern of *Thunnus albacares* (yellow fin tuna) revealed abundance of small sized fishes in deeper area, while the larger individuals showed aggregation near the inshore areas at 30 m depths.

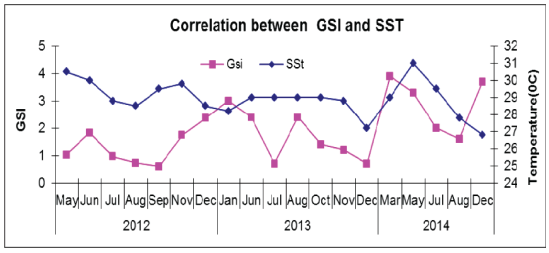
Effect of SST on Pelagic Fishes: Strong association was found between the monthly average of percentage of maturity data of Ribbon fish (from 2007 to 2014) with corresponding night SST. Pearson's correlation between percentage of maturity and length at maturity of three pelagic fishes viz., Bombay duck (*Harpadonnehereus*), Indian Mackerel (*Rastrelliger kanagurta*) and Ribbon fish (*Trichurus lepturus*) shows that the variability in temperature negatively influences the length at maturity of Bombay duck (r value -.773, $p< 0.05$) and Ribbon fish (r value -802, $p <0.05$). The correlation was both negligible and insignificant in case of Indian Mackerel.



Correlation between GSI and SST for *S. indicus*

Climate change impact on trawl catch rates: SST plots show a 0.4 ^{O}C (average SST 28.38 ^{O}C) rise in temperature for Andhra Pradesh, 0.9 ^{O}C (average SST 28.33 ^{O}C) for Orissa and 1.0 ^{O}C (average SST 27.97 ^{O}C) for West Bengal from 1960-2010. Increasing catch rates in trawls were observed with decreasing SST along the NE coast of India. Average annual chlorophyll-a values were the highest for West Bengal with an average value of 4.04 mg/m^3, followed by Orissa with 1.27 mg/m^3 and Andhra Pradesh with 0.47 mg/m^3. Peak chlorophyll-a values were recorded from July-September for Andhra Pradesh, July-November for Orissa and August-December for West Bengal during 1997-2010.

Comparison of GSI, HIS and sex ratio with environmental parameters: The GSI of *Stolephorus indicus* and SST showed significant positive correlation. The GSI of *S. indicus* and bottom salinity from 15 m depth also showed significant correlation.

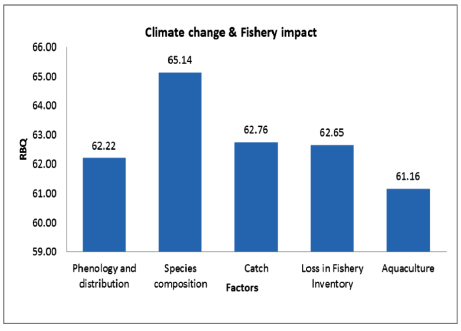


Reproductive biology and trophodynamics of fishery: Studies on biology and trophodynamics of Indian oil sardine, Indian mackerel, yellowfin tuna, skipjack tuna, barracuda, ribbonfish, threadfin bream, goatfish, croakers, lizardfish, penaeid prawns and squid showed a lower mean length, maturity percentage and gonado somatic index for most of the species at Visakhapatnam, Andhra Pradesh and higher at Digha, West Bengal.

Spawning activity of fishes along north Tamil Nadu coast: Reproductive indices estimated for four major fish species (Indian oil sardine, Indian mackerel, Japanese threadfin bream and ribbon fish *Trichiurus lepturus)* shows that the size at first maturity as 209.7 mm for *R. kanagurta*, 172.4 mm for *S. longiceps*, 618.8 mm for *T. lepturus* and 145.9 for *N. japonicus.* The occurrence of adult *N. japonicas* showed positive correlation with rainfall and low temperature regimes.Adults were pre-dominant in the samples of S. *longiceps*, *N. japonicus, T. lepturus*. Sub adults and maturing individuals were found to be predominant in *R. kanagurta* collections. Dominance of these size groups on a continuous basis could be detrimental to *R. kanagurta* stocks in the region since the individuals are deprived of the chance to breed at least once, and the spawning stock biomass will diminish.

SST and spawning biology of the Japanese threadfin bream (*Nemipterus japonicas*): During 2011-2013, the average SST during April-September was 29.9°C at Chennai and 26.7°C at Mangalore while during October-March it was 27.8æ%C at Chennai and 27.3°C at Mangalore. Comparing the SST at the two places, we find that the average SST off Chennai is always higher than that off Mangalore. However, corresponding to much higher SST during April-September off Chennai, the proportion of spawners was only 12.1% at Chennai, as against 60.1% at Mangalore..

Vulnerability Assessment: The impact of climate change on the five different parameters viz, Demography, Occupation, Infrastructure, Climate components and Fishery components in coastal villages of Tamilnadu and Andra Pradesh were assessed using the application of PARS methodology and it was indicative that climate change has mostly impacted fishery followed by economic and environmental factors in coastal villages.



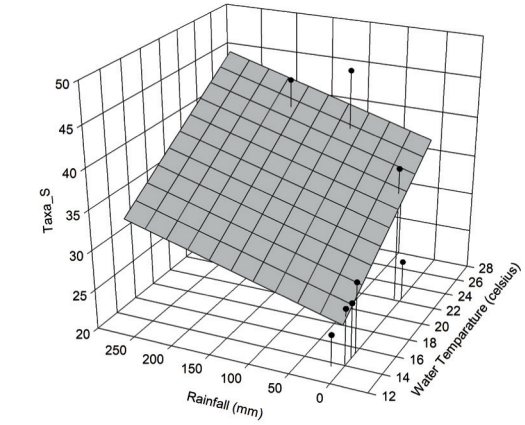
Carbon Footprint in Life Cycle of Marine Fisheries: Carbon footprint contribution of marine fisheries activities at selected fishing harbours of Andhra Pradesh and Tamil Nadu were estimated. Mechanized catches contributed 80 – 85 % of the total fuel burnt and 79 – 90 % of the total electricity consumed. The harvest phase (88 – 93 %) burnt the most fuel, while the post harvest phase (51 – 62 %) contributed the most to the electricity consumption. Emission intensity per kg of marine fish was 0.34 kg C and 1.26 kg CO_2 in Visakhapatnam. Fuel and electricity consumption and emission intensity was high for mechanized landings and low for motorized landings. The highest emissions were recorded in the harvest phase at all the places of Andhra Pradesh.

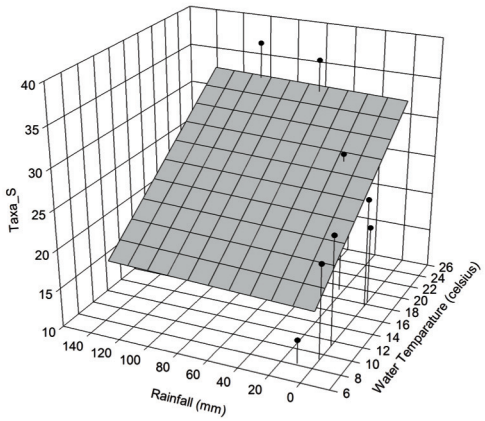
In Chennai Fisheries Harbour total carbon footprint during 2012 was 64 million kg CO_2e. Mechanized sector emitted 60.65 million kg CO_2e (94.5 % to total) and motorized sector contributed 3.53 million kg CO_2e. Harvest phase emitted 89.7 % of total carbon followed by post-harvest phase (5.59 million kg CO_2e) and pre harvest phase (1.02 million kg CO_2e). Emission by motorized fishing was 0.17, 2.85 and 0.51 million kg CO_2e at pre harvest, harvest and post-harvest phases respectively.

In Tuticorin the average quantity of diesel consumed during a year was worked out as 20.3 million litres which emitted 54.1 million kgCo2e. Out of the total emission, 72 % was from fuel combustion for fishing. The average production was 41914507 kg. Thus the average carbon foot print from trawl fishery resulting from all the above mentioned activities was found out as 1.77 kgCo2e per kg of fish caught.

Climatic variation and Fish assemblage pattern (CIFRI)

Climate variability had influenced the fish composition and recruitment in river Ganga and a significant decline in recruitment of Indian major carps have been observed with 55 fish species at Patna and 75 fish species at Farakka. Dominant catfish species in Ganga River at Patna were *Gagata cenia*, *Ailia coila*, *Gagata sexualis*, *Eutropiichthys vacha* etc., whereas at Farakka were *Ailia coila*, *Gagata cenia*, *Bagarius bagarius*, *Eutropiichthys vacha* etc. The most dominant order was *Cypriniformes* followed by *Siluriformes* and *Perciformes* in both the places. Fish species diversity (Taxonomic richness, Simpson's index, Shannon weaver index) was significantly related with the climatic variables (water temperature and rainfall). Among the two climatic variables (*i.e.* - water temperature and rainfall), a significant ($P < 0.05$) positive correlation has been observed between fish biodiversity indices (taxa richness, Simpson's index, Shannon weaver index) and water temperature.





Fish species diversity (Taxonomic richness) with climatic variables. ***Left panel indicated for Farakka and right panel indicated for Patna. Increasing trend plane indicates positive correlation with climatic variables (Water temperature and rainfall)***

Spawning period and Gonado Somatic Index (GSI) in relation to climatic variables for some cold water species: In case of *Schizothoraxrichardsonii* (snow trout), September-October. Peak value of GSI was observed in the month of September for males and October for females when the temperature ranged between 13 to 14.5^{0}C in the Alaknanda River near Karnaprayag, Uttrakhand. In case of *Tor putitora* spawning was observed from May-August. Peak value of GSI was observed in the month of July and August for male and female respectively when the temperature ranged between 21^{0}C to 23^{0}C in the KosiRiver.

Historical analysis of alterations in fish species composition:: Study of the historical record of River Cauvery downstream of Mettur reservoir indicated that the share of major carps in the total fish catch was in the range of 57.9 to 86.6% in 1950s (1953-54 to 1960-61) which declined to 30.7 to 46.6 % in early 1990s (1991-92 to 1993-94). *Cirrhinus. Cirrhosa* constituted 55% of catch in 1953-54 but declined to less than 20% in 1969-70. *M. aor* and *W. attu* formed more than35% of catch in 1964-65 but reduced to less than 10% during 1992-93. *Tor khudree*, *Neolissochilushexagonolepis, P. carnaticus*and*L. kontiuswere* reported to have disappeared since 1995 but *L. kontius* and *P. carnaticus* have been reported in the fishery during 2014-15. Exotic fishes like *Cyprinuscarpio* are encountered in the fishery since 2000 and *O. mossambicus*and *O. niloticus* are reported in the river since 2004. *Pteroglypthichthysdisjuntivus* was recorded for the first time in 2014. The fish catch composition shows that the transplanted fish *Catlacatla* successfully established in this river.

Impact of climate related flow alterations on fish diversity: Investigations were conducted during early post-monsoon in river Mahanadi covering a stretch of 365 km

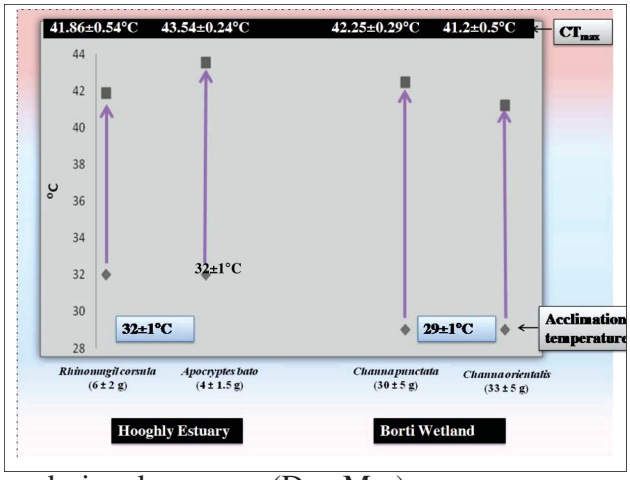
between Hirakud and Zobra barrages representing upper, middle and lower zone. The upper zone was represented by rocky substratum with an average temperature of 26.0±0.5^{0}C with 45.83% fish species belonging to *cyprinidae* followed by *gobidae*(33.3%) and *ambassidae* (16.6%). The middle zone was represented by muddy and sandy bottom with an average temperature of 30.0±0.5^{0}C with 53.8% by *cyprinidae*followed by *bagaridae*(30.7%)and *sisoridae*(15.38%).The lower zone was represented by sandy bottom with an average temperature of 33.0±0.5^{0}C with 58.97% fish species belong to *cyprinidae* followed by *clupeidae* (12.8%) and *bagaridae* (10.26%). This indicates, the lower zone provides better species diversity than the middle and lower stretch.

Impact of climate related water stress on fisheries of floodplain wetlands: *A*ssessment of climate change on fisheries of floodplain wetlands in four water bodies from two districts of Assam shows considerable variation in presence of different fish species and their percentage contribution in the total catch of the beels. In general, catch of Indian major carps reduced mostly because of loss of riverine connectivity, and minor and small fishes occupied the niches. Minor and small groups of fishes were represented by Mola, *Puntius*, *Mystus*, *Channa*, *Gudusia* etc. Analysis showed that *Mystus* contributed 50% to the total catch in Bajduwarkahbuli, whereas *Puntius* contributed 35% in Gurguri-Barsingabeel. *Gudusiachapra* contributed 44% of the naturally occurring fishes in Borpetabeel. Studies further showed a declining trend in the occurrence of IMCs (*Labeorohita, Catlacatla*and*Cirrhinusmrigala*), and *Chitalachitala*in all the beels over the past years. Low water levels due to prolonged dry seasons had significant effect on the decline of these species from the wetlands.

Carbon sequestration potential in wetlands: Jhagrasisa is a sewage fed Ramsar site wetland situated in East Kolkata, while Khalsi and Akaipur are oxbow lake type, river connected wetland situated in District Nadia, West Bengal. Study on potential of carbon (C) sequestration of these wetlands shows the accumulation of C upto 0-15cm layer in one hectare was around 24.7MgC/ha (1Mg=1tonne) in Jhagrasisa, 70.3MgC/ha in Khalsi and 26.64MgC/ha in Akaipur. The corresponding figures in 15-30cm layer came out to be 15.37, 62.44 and 25.13 MgC/ha. When C pool in the two layers are combined i.e. up to 30 cm depth, Jhagrasisa and Akaipur wetland stored about 40.07 t C/ha, 51.77 t C/ha respectively, where as Khalsi s much higher i.e.132.74 t/ha. Comparatively, more carbon was found to be accumulated in Khalsi than Akaipur and Jhagrasisa wetland which might be due more primary production.

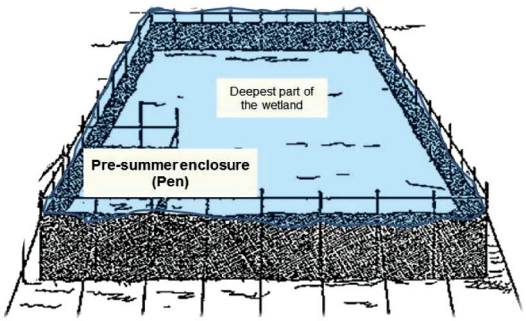
Thermal tolerance limits of fishes: Upper thermal limits (CTmax) of estuarine fishes from Hooghly were 41.86± 0.54 °C and 43.54 ±0.24°C ($p<0.01$) for *Rhinomugilcorsula* and *Apocryptesbato,* while same were 42.45±0.29°C and 41.2 ± 0.5°C ($p<0.05$) for wetland fishes *Channapunctatus* and *Channaorientalis* respectively. *Apocryptesbato*is most tolerant fish species followed by *Channapunctatus* indicating their better survival potential than other two species in future temperature scenario.

Adaptation measures to mitigate impact of drought on fisheries: Prolonged dry periods adversely affect fish retention or stocking in the beels, hence some adaptive measures are advocated to fisher folk



(a)***Creation of deep pools in the beel***: In order to overcome the decreasing water levels during winter season, many beel managers used to create one or more deep pools by digging in the beel to allow fishes to survive and grow during dry season (Dec-Mar).

(b) ***Net pen enclosures***: To sustain livelihoods during dry months, beel fishers install net pens of varying sizes in the deeper portions of the beels to stock and rear fishes.



(C) ***Temporary pre-summer enclosure*:** A provision of enclosure/pen is made around the deepest part of the beel during pre-summer as the water level starts to recede. The commercially important fishes are deliberately restocked within the enclosure The fishes are harvested from the enclosures intermittently based on size.

Impact climate variables on aquaculture: (CIBA)

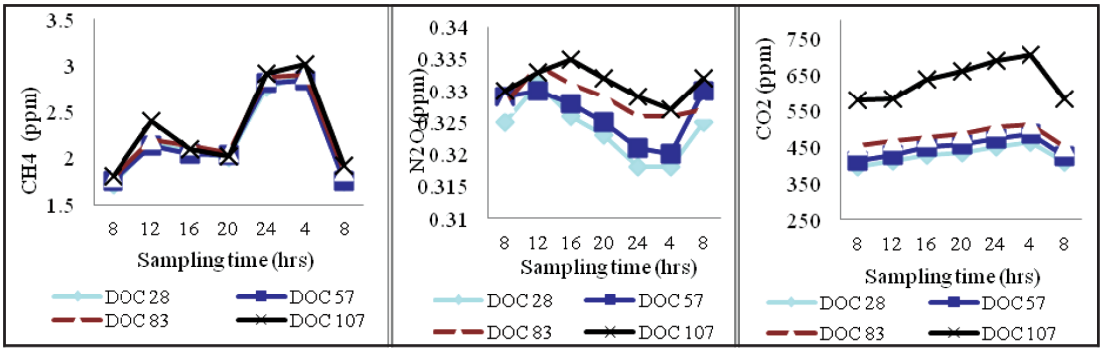
Climate change events and the physical and economic impacts perceived by the aquaculture farmers in west coast states (Maharashtra, Goa & Karnataka) were obtained through in-depth questionnaire survey and through organization of focus group workshops (FGW) at Palghar (Maharastra), Goa, Kumta and Kundapur (Karnataka).The crop calendar in relation to month-wise weather events were mapped for each district. Risk matrix of climate change events and their impact on aquaculture indicated that high temperature and tidal amplitude in Kundapur (Karnataka) and heavy rainfall (July-Aug) and low temperature (Dec-March) in Goa are disastrous to aquaculture.

Sea Level Rise (SLR) and Prediction of Inundation: Area of inundation of different land resources including aquaculture was predicted using geo spatial techniques at 50 cm and 100 cm SLR for Alapuzha district, Kerala and Navsari and Surat districts of Gujarat. The predicted submerged area for agriculture and aquaculture in these districts at 1 m

SLR was 15521 and 70 ha out of 101336 and 606 ha in Alapuzha district and 296 and 153 ha out of 155979 and 3109 ha in Surat and Navsari Districts, respectively.

Collection of GHGs from fabricated glass jars

Aquaculture and Greenhouse gases (GHGs) emissions: Emission of all the three GHGs increased with the days of culture in both shrimp and finfish cultured ponds, except for CH_4 in Seabass *(L. calcarifer)*. Salinity has inverse relationship with methane emission whereas no significant difference among water salinities with respect to N_2O and CO_2 emission. Nitrous oxide emission from seabass culture ponds was very less compared to shrimp culture ponds. Positive correlation of CO_2 and CH_4 was observed with SOC and Microbial biomass carbon (MBC). Diurnal fluctuation in greenhouse gases emission was observed. Methane emissions were high at 4 hrs in the early morning due to anoxic conditions, decreased at 8 hrs and again increased during day time depending on temperature in the *L.vannamei* culture ponds with stocking density of 44 nos./m^2. Carbon dioxide emission increased gradually from 8 hrs during the day and higher value was recorded at 4 hrs in the morning. On the contrary, high values of nitrous oxide were recorded during the day compared to night. A positive correlation was observed between the protein percentage of the feed and nitrous oxide emission.



Diurnal variation in GHGs emission

Aquaculture and carbon sequestration: Assessment of total carbon accumulation in shrimp culture pond over a period of eight crops for four years indicated that sequestration of 2.4 tons of carbon/ha could be possible through the increase in soil carbon.

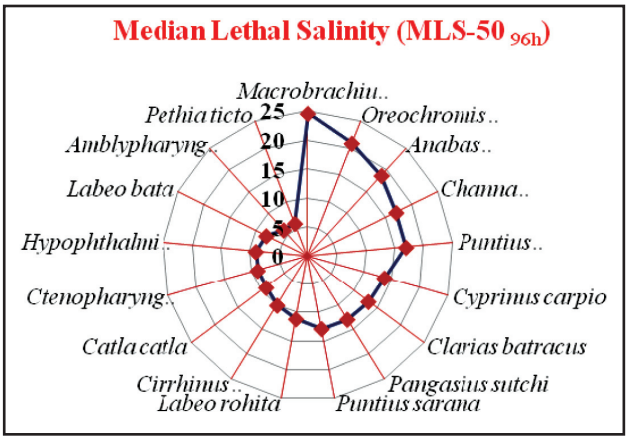
Climatic variability and reproductive performance: Shrimp (*P. monodon*) breeding and reproductive performance in hatchery was better at 27-28°C and 29-30°C than at 33-

34°C. Higher maturity and spawning (37 and 26%) were observed at 29-30°C than at 27-28°C (27 and 20) and 33-34°C (13 and 10 %). Vitellogenin gene showed maximum up-regulation in shrimps maintained at 29-30°C and marginally expressed (0.4 fold decrease) in shrimps maintained at high elevated temperature (33-34°C). Similar profiles were observed for Hsp70 and Hsp21

Impact of Climate change on aquaculture and coping measures (WBUAFS)

Survey of 451 fish farming households (244 households spread across 9 Gram Panchayats in Sagar block and 207 households from 11 Gram Panchayats of Basanti block of Indian Sundatban) revealed that the fishponds in low-lying areas of Gangasagar, Dhablat, Ramkarchar, Daspara Sumati Nagar and Ghoramara Gram Panchayats of Sagar block are prone to coastal flooding. It leads to breach of pond dyke, ingression of saline water into freshwater pond, escape of fish stock from the pond, entry of other (often unwanted) fish species, fish mortality *etc*. Basanti block which is located in eastern sector of Indian Sundarban, is also prone to cyclone and storm surge. Ponds located at Jharkhali and Nafargunj Gram Panchayats of Basanti block are sensitive to saline water inundation during monsoonal storm. Risk analysis of climate induced threats associated with aquaculture revealed that in both Sagar and Basanti blocks, farmers considered breach of pond embankment, mortality of fishes due to saline water ingression as extreme risk; escape of fish stock and diseases as high risk; entry of unwanted species, retardation of growth and deterioration of water quality as medium risk; and damage of pond environment as low risk. To reduce the threats against saline water ingression, farmers are taking some coping measures like increase in pond dyke height; repair and strengthening of dyke; plantation on dyke; dewatering and addition of fresh/rain water; application of chemicals/ lime/ dung; addition of tree branches in pond for hide outs *etc*.

Tolerance fish species to abiotic climate change: The Median Lethal Salinity (MLS-96 h) test conducted for seventeen freshwater aquaculture candidate species using Probit method reveals that Median Lethal Salinity (MLS-50 $_{96h}$) is highest for Macrobrachium rosenbergii (24.6 ppt) and lowest for Pethia ticto (6.12 ppt).



Natural adaptive capacity of freshwater aquaculture to salinity: Growth performance study at various salinities (0, 5, 10, 15, 18 and 20 ppt) conducted for one month duration to evaluate the adaptive capacity of some freshwater aquaculture candidate species indicate that fishes like Labeo rohita, Cyprinus carpio and Systomus sarana tend to naturally adapt till 5 ppt salinity but show significant retardation in growth ($P<0.05$) at 10 ppt salinity. In case of Macrobrachium rosenbergii tend to naturally adapt till 15 ppt salinity but showed significant retardation in growth at 20 ppt ($P<0.05$). Oreochromis mossambicus was found to naturally adapt till 15 ppt salinity but showed significant growth retardation at 18 ppt ($P<0.05$). The observed growth retardation might be due to depressed appetite and increased osmotic stress at higher salinity

Adaptation strategies for salinity stress:

a) Feed manipulation: In case of *Cyprinus carpio* at 5ppt, high energy feed exhibited significantly ($P<0.05$) better growth than normal feed. Further improvement in growth was observed when high energy feed was fortified with either immunostimulant (Immutron contains Oligomanans, modified amino acids, natural pigments from marine algae, inulin, other immnopo-pentiators and bioactive ligands) or gut-probiotics. Similar trend was found at 10ppt salinity level. *Oreochromis mosambicus* fed with high energy feed at 10 and 15ppt salinity ppt had significantly ($P<0.05$) better growth than fish fed with normal feed. Further enhancement in growth was observed when high energy feed was added with either immunostimulant or gut-probiotics. In *Labeo rohita* at 5ppt and 10ppt salinity high energy feed exhibited significantly better growth ($P<0.05$) than normal feed. Moreover, additives like immunostimulant / probiotic / prebiotic alongwith high energy feed further increased the growth rate in salinity stress. High energy feed fortified with immunostimulant showed best growth ($P< 0.05$) followed by probiotics and then prebiotics.

b) Aeration : Aeration as an adaptation strategy against different salinities (0, 5 and 10 ppt) for two freshwater fish *Cyprinus carpio* and *Systomus sarana* under wet laboratory conditions indicated that in both species, aeration had positive effect on growth and survival only at 5 ppt salinity stress.

Effect of saline water flooding on freshwater species: Saline water flooding (resultant salinities of 5, 10, 15 and 20 ppt) studies on cultivable freshwater species (*Labeo rohita*, *Cyprinus carpio*, *Systomus sarana*, *Cirrhinus mrigala, Labeo bata, Ctenopharyngodon idella, Catla catla, Barbonymus gonionotus, Hypophthalmichthys molitrix, Channa punctatus* and *Macrobrachium rosenbergii*) under field conditions indicated that *Macrobrachium rosenbergii* was the most tolerant species with no mortality even at 20 ppt.

Composite Climate Resilient Ranking (CCRR) of different freshwater species

Freshwater species	Salinity Tolerance Rank based on survival after saline water flooding	Growth Rank based on body weight gain at 5ppt	Composite Climate Resilient Rank (based on tolerance & growth)
Macrobrachium rosenbergii	1	2	1
Cyprinus carpio	4	1	2
Barbonymus gonionotus	3	3	3
Labeo rohita	6	4	4
Catla catla	9	10	5
Systomus sarana	5	9	6
Cirrhinus mrigala	7	11	7
Ctenopharyngodon idella	8	5	8
Labeo bata	11	6	9
Hypophthalmichthys molitrix	10	8	10
Channa punctatus	2	7	11

Climate Adaptive Integrated Farming: Livestock-crop integration with aquaculture as Climate Adaptive Integrated Farming (CIAF) has been tried among the marginal fish farmers of Sundarban in participatory mode. Incorporation of salt tolerant fruits and horticultural crops with salt tolerant aquacultural species has resulted in better economic

returns, capacity enhancement and reduced risk. This has been achieved through land shaping, reclamation, re-excavation of ponds including 3-tier step-cutting or terracing on inward-slopes of the ponds. Plantation on the top of the dyke has resulted in its strengthening. This has also given additional (70-90% more) income to the farmers through agri-horti-cultural crop. The intervention showed encouraging results with increased production and profitability through recycle of waste, better utilization of space and manpower and crop diversification.

4.8 Socio-Economic Impacts and Community Response

Assessment of vulnerability and adaptation to climate change (CRIDA)

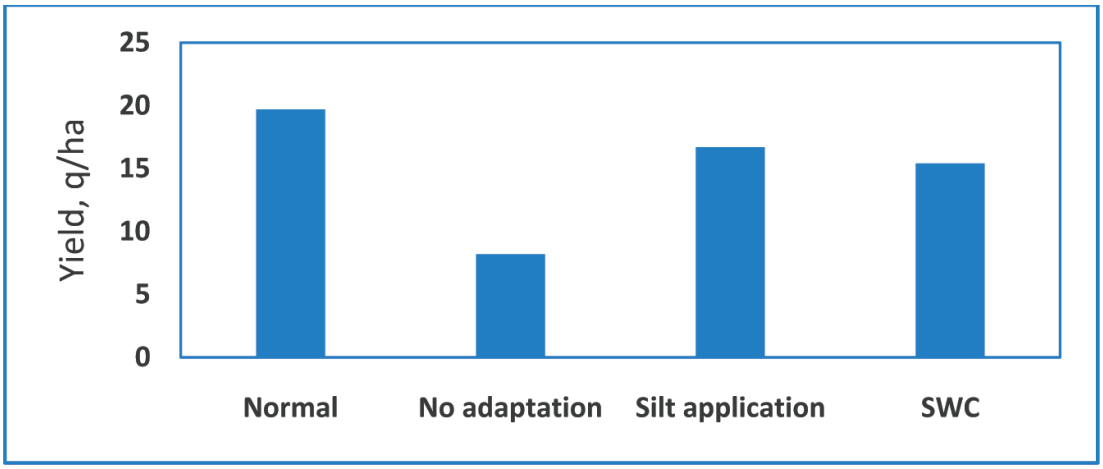
Using the primary data, the household level vulnerability was assessed in Anantapur district and the key characteristics of households with high vulnerability were identified. It was observed that households with less access to irrigation, poor social capital, low remittance income and low livestock endowments were more vulnerable. Similarly, most farmers with high vulnerability were relatively less educated and older in age. The analysis would be useful in identifying the households with high vulnerability and thus better target interventions and incentives.

Key features of households with varying vulnerability, Anantapur, 2014-15

Variable	Vulnerability		
	Low	Medium	High
Age (years)	41.80	47.87	49.94
SC/ST population (%)	0.00	13.3	12.5
Education (years)	9.67	4.20	2.00
Family size (no/HH)	5.60	5.33	4.81
Working males (%)	42.00	39.87	41.71
Membership in CBO (%)	87	80	56
Remittance income (%)	18.24	10.41	5.82
Farm size (ac)	10.02	5.27	4.05
Irrigation (%)	57.93	34.96	4.91
Cropping Intensity (%)	103.55	94.60	90.63
Having large ruminants (%)	2.27	2.27	1.50
Having small ruminants (%)	23.73	7.00	5.31
HH assets (Average %)	55.76	45.45	39.77
Farm assets (Average %)	31.28	11.79	5.77

The impact of various adaptation interventions on economics and resilience was also examined in at Baramati, Pune district. It was observed that the adaptation intervention in the form of application of silt and in situ moisture conservation measures protected yield of sorghum during the drought. These two interventions gave 85 and 78 per cent of normal yield and were proved to enhance resilience. Also, income resilience was found

to be more when the livelihoods are more diversified. However, the analysis also hinted at possible lower income with more diversification in 'normal' years.



Effect of adaptation interventions on yield during drought, Baramati, 2014-15

Vulnerability assessment and evolving adaptation strategies for climate resilient agriculture in semiarid regions of Tamil Nadu and Puducherry (MSSRF)

The project was implemented in two sites in Illuppurtaluk of Pudukkottai district, Tamil Nadu and 3villages in Mannadipet Commune of Puducherry covering an area of 500 ha. for each site. The interventions are also being expanded into third site, the semiarid regions of 8 villages in Mailam block, Villupuram district, Tamil Nadu.

Resilient crop varieties were identified by conducting participatory variety selection trials at Pudukkottai. VBN-4, VBN-5 and ADT-5 (black gram), VBN-2, VRM-1 and CO-6 (greengram) and ASD-19, TM-07335, ADT-36 and CO-51 (rice) were identified to have better characteristics for climate resilience. In Puducherry also, suitable crop varieties were identified in case of rice (TMO-5091, ADT-37), black gram (VBN-4,6, ADT-5), green gram (VRM-1, CO-7) and red gram (UPAS-120 and VBN-2). In Villupuram, rice variety TMO-7278 treated with urea super granule was found to give highest yield (70.75q/ha). Use of urea super granule was chosen as it would enhance the fertilizer use efficiency under flood conditions. In Pudukkottain, green gram showed superior performance and can replace blackgram especially during failure of north-east monsoon. Depending on the monsoon, it can be grown as a grain crop or green manure crop.

Participatory technology development was conducted in project sites on various aspects of crop cultivation in rice, pulses and horticulture. As part of the programme, farmers' filed schools were conducted and a group of farmers was developed to act as resource persons to train other farmers.

Meeting Challenge of Climate Change through Integrated Mitigation & Adaptation for Sustainable Agriculture: through community based, locally adapted strategies, & Leadership (NCCSD)

This study was initiated to assess the knowledge of farmers with respect to climate change and its impact and management in agriculture in three districts, viz., Kutch, Anand and Navasari of Gujarat. The project is also focused on building capacity of farmers and other stakeholders in promoting climate resilient agriculture. Training material in the form of posters, documentary film in Gujarati & English and a guidebook in Gujarati were prepared by covering various aspects related to agriculture, horticulture, livestock management. A number of training programmes were conducted to train farmers and extension agents in the three districts chosen for the study. The feedback received from the trainees and other experts revealed that the training programmes were useful and indicated that there was a need for more frequent interactions with the stakeholders to spread the information and skills on climate resilient agriculture. The analysis also showed a positive impact of training on knowledge levels and adoption as compared to untrained farmers.

Documentation of indigenous coping strategies to climate change in different areas of agriculture with special reference to drought prone areas of Andhra Pradesh and Karnataka (ABF)

Documentation of traditional and indigenous knowledge related to climate and the related resource and crop management activities have been focussed. During the year, literature on traditional cropping systems, traditional soil management practices, traditional plant protection practices and traditional socio-institutional adaptations to climate change was collected and and reviewed to develop research framework for the execution of case studies on relevant themes in Anantapur and Bellary districts. Case studies on traditional cropping System, soil management, plant protection practices and socio-institutional adaptations to climate change were completed in Anantapur and Bellary districts.

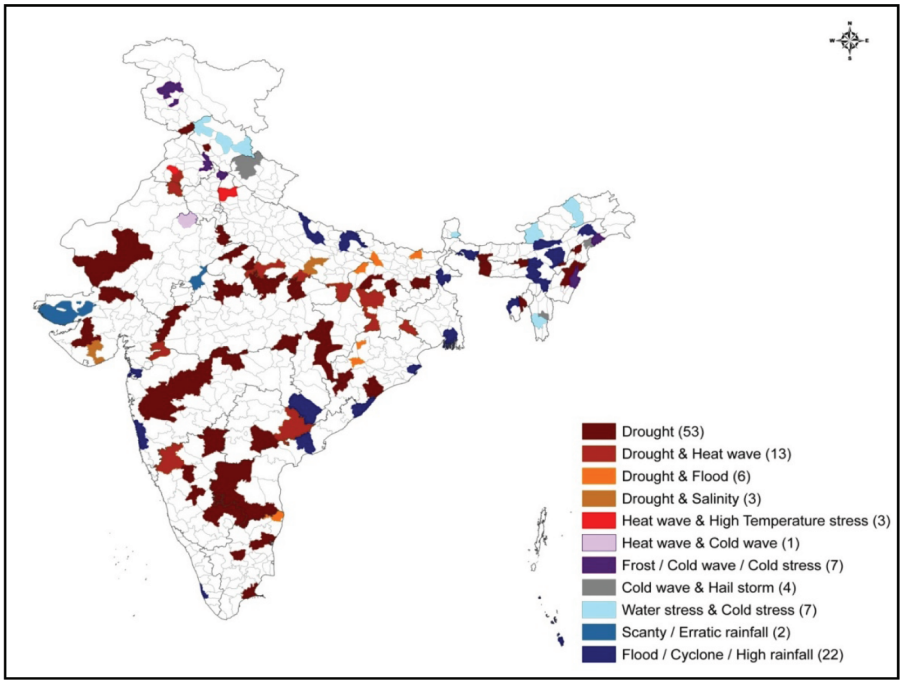
Traditional farmers followed practices like tank silt application, anthill soil application, application of alluvial sediments to change the soil texture for retention of soil moisture and easy percolation of rain water. In view of soil fertility improvement, application of the forest humus, usage of wild plants and trees as green manure was used. The traditional practices like construction of bunds with soil or semi-solid materials like strengthen the bunds, construction of 'Sappillu' (a bridge like construction built with rocks without cementing material between rocks) in gully areas to prevent soil erosion.

The practices like mixed cropping of cereals with legumes and oilseeds in inter cropping pattern, periodical crop rotations, sequential geometrical alternations in sowing patterns, crop selection based on the sowing period that pertained to the traditional agricultural calendar are the major features of the traditional cropping systems evolved in the study regions.

5.0 Technology Demonstration in Climatically Vulnerable Districts

Technology demonstration component (TDC) under NICRA addresses demonstration of appropriate technologies and practices to enable farmers cope with current climate variability. Demonstration of available locations specific technologies related to natural resource management, crop production, livestock and fisheries is the primary objective for enhancing adaptation gains and mitigation potential for building climate resilience.

Technology demonstration component (TDC) under NICRA is being implemented in a farmer participatory mode through in 100 vulnerable districts of the country through 100 Krishi Vigyan Kendra's (KVKs) spread across the country in 8 Zonal Project Directorates. Twenty one additional districts have been added for implementation of TDC in the XII Plan taking the total to 121 districts. Transfer of Technology Divisions of seven core partner ICAR institutes under NICRA viz., IARI, NDRI, IIHR, CMFRI, CIAE, ICAR NEH and CRIDA also implemented the technology demonstration component.



Natural Resource Management Interventions

Enhancing the available water through surface and sub-surface storage structures is one of means of creating resilience at the local level for agricultural systems. This is especially important in low to medium rainfall zones as rainfall variability and occurrence of intense rainy events are considered to be high. A multi-pronged approach was adopted which includes the creation/renovation of community tanks, check dams, individual farm ponds, desiltation of conveyance systems for safe disposal of excess rain into community tanks,

in-situ conservation of rainfall through soil and land management practices. Village climate risk management committees (VCRMCs) in NICRA villages played an important role in the participatory decision making on the site specific natural management interventions to be taken up in the village.

In 2014-15, renovation/ de-siliting of existing rainwater harvesting structures and creation of new ponds/ Jalkunds were taken up to improve storage of rainwater and its efficient use both in kharif and rabi crops to enhance resilience and increase cropping intensity in about 1400 ha. In situ conservation practices were taken up by farmers in NICRA villages using appropriate farm implements through adoption of ridge furrow, broad bed furrow and furrow irrigated raised bed planting methods. Crop residues were used for mulching in high value crops such as winter vegetables in rice fallows. Zero till sowing in several rabi crops was taken up for advancement in sowing date to avoid high temperature stress at flowering and maturity stages, conserve soil moisture and reduce number of irrigations. Happy seeder sown zero till wheat suffered relatively less lodging damage (<5%) and shorter period of water logging (< 2 days) as compared to severe damage (>50%) and water logging of up to 7 days in conventionally sown wheat in Punjab and Haryana due to unseasonal rains during March, 2015.

During *kharif*, farmers in several districts in Andhra Pradesh, Telangana, Maharashtra, Gujarat, Rajastha and West Uttar Pradesh experienced delayed monsoon onset and deficit rainfall conditons. Harvested rainwater and its efficient use enabled farmers to provide life saving and critical irrigations to rainfed crops and use the stored water for increasing the cropping intensity in *rabi*.

In Takali (BK) village of Amravati district, In-situ soil moisture conservation practices in soybean in 80 ha covering 125 farmers in Takali village, Amravati gave up to 37 increase in yield under deficit rainfall conditions during *kharif*, 2014. Renovation of 13 cement plugs and 7 farm ponds of different water storage capacity was undertaken by farmers and this helped in recharging the surrounding open wells. Desilting of these structures increased percolation of impounded water leading to increase in water table by 2.5' to

Renovation of check dam increases water table and storage in open wells for irrigating *rabi*

4.3', water availability for irrigation by 13% and area increased by 17% during 2014-15. Renovation of rainwater harvesting structures since inception of the NICRA project could expand the area under irrigation in the village during *rabi* to 120 ha.

In East Singhbhum, monsoon onset was delayed by 10 days with deficit rainfall conditions in June (-51%) and September (-39%) which affected timely raising of paddy nurseries in the district. In the NICRA villages of Barunia and Pathergora, farmers with their fields adjoining the renovated check dam could prepare paddy nursery (var. Naveen) by 15th June and transplant in the main fields by first week of July compared to other farmers who could transplant only by 18th July. Farmers were able to provide critical irrigations to the crop in 15 ha area during dry spells in August (tillering stage), September (panicle initiation and flowering) and November to December (maturity stage) and realized an yield advantage of 17 q/ha.

Renovated check dam facilitates timely nursery and transplanting of paddy in East Singhbhum

In Bhalot village of Kutch, farmers face erratic and scanty rainfall. The village received 375 mm rainfall during 2014-15 season, which was 145 mm less than the decadal average. However, farmers with recharged open wells adjoining 3 stop dams constructed in the

Recharging of open wells enables timely planting of Bt Cotton under drip irrigation at Kutch

village could take up timely sowing of Bt cotton under drip irrigation with an yield increase of 26%. Seeing the success of recharged open wells coupled with efficient use through drip irrigation, 82 farmers in the village adopted the practice in 108 ha area which is significant increase from adoption by 12 farmers in 13 ha area in the first year.

In Barodi village of Datia, rainwater storage capacity of 18000 and 51000 cubic meter was created through renovation of 3 farm ponds and 3 check dams during 2014-15. It brought about crop diversification, facilitated life saving irrigation to *kharif* crops and increased cropping intensity in *rabi* crops. Efficient use of farm pond water through sprinklers and rain gun in *kharif* and *rabi* crops increased the net returns and doubled the cropping intensity. Pre-sowing irrigation through micro irrigation to mustard using harvested water practiced by 118 farmers in 128 ha, which resulted in an average yield of 16.3 q/ha and net returns of Rs.36800 with a BC ratio of 3.2. The harvested water was available up to December month and raised the water level of 28 wells. Additionally, 15 ha area could be irrigated through wells. Cultivation of high value crops such as tomato, chillies, brinjal and cauliflower through farm ponds and check dam along with micro irrigation enhanced yields and additional income ranging from Rs.79000/ha to Rs.148000/ha with BC ratio ranging between 4.2 - 5.6.

Rainwater harvesting promotes crop diversification and enhances productivity at Barodi village of Datia

Conservation agricultural machinery was demonstrated in 170 ha in Kachhiderekheda village. Economic impact of broad bed planter demonstration during *kharif* and *rabi* seasons inidcated an increase in net income of farmers by 56.6 and 27.4 percent in soybean and wheat crops, respectively. Three machines under TDC, NICRA viz., rotary assisted bed maker-cum-seeder, straw collecting–cum-disbursing machine and raised bed seeder. Rotary assisted bed maker-cum-seeder was commercialized to M/s TAFE Chennai on 31 July, 2014 by CIAE.

Crop Production

During 2014-15, farmers in drought affected districts in Andhra Pradesh and Telangana took up early sowing of crops such as cotton and maize with the receipt of early rains in June. However, subsequent prolonged dry spell led to re-sowing especially in cotton while short duration pulses such as greengram and black gram could not be sown till end of June. Late receipt of rains in July led to delayed planting of dominant *kharif* crops of soybean and cotton in Maharashtra beyond 15th July. Farmers adopted contingency crops such as sesame, sunflower, early chickpea. Farmers in West Uttar Pradesh, Gujarat and Rajasthan adopted direct seeding of paddy and sowing of alternate crops such as blackgram, sesame, castor, moth bean, cluster bean, fodder crops and early *rabi* crops like *Toria*.

Monsoon contingency action plans were prepared and implemented by 60 NICRA KVKs in districts experiencing delayed onset/ deficit rainfall conditions during *kharif* 2014-15. Contingency crop plans for late planting (after mid July) along with crop, soil moisture, nutrient management measures in standing crops were taken up in NICRA villages.

Short duration and drought tolerant varieties were demonstrated in farmers fields in all major rainfed crops. The varieties include: soybean (JS-95-60, JS 93-05), pigeon pea (ICPL-88039, BDN-711, NDA-1, TJT-501, PRG-159, BRG-2 & 4, ICPL-87, maize (GM-6, HQPM-1 & 7, JM 216, Birsa Makka-1), short duration pulses (Samrat, Vishal, Azad-3, BBN-3, TGM-3, RNG-344, TARM-1), finger millet (ML-365, GPU-48, GPU-28, A 404), paddy (Naveen, Sahbhagi dhan, Basanti, Birsa Vikas Dhan, MTU-1010, NRC-7, MAS-26, Pusa Basmati 1509.

Intercropping soybean and pigeonpea (6:1) area gave a yield of 15 q/ha of soybean. Short duration soybean variety (JS-93-05) lead to a yield advantage of 22% over long duration variety. Contingency crops sesame (Madhuri) and sunflower (PKV 559) for delayed planting also proved effective.

Intercropping of soybean with pigeonpea

Intercropping of soybean with pigeonpea

Short duration varieties of paddy (Lalat & Anjali) after green and brown manuring with Sesbania demonstrated in 36 farmers fields gave an yield advantage of 18 - 20% and B:C ratio of 1.49 to 1.67 over farmer's practice at Gunia village, Gumla, Jharkhand. Direct seeding of rice with Lalat variety gave a yield advantage of 14% with B:C ratio of 1.72. Contingency cropping of Niger (Birsa Niger-3) was demonstrated to 20 farmers with an average yield of 4.1 q/ha.

Niger at Gumla, Jharkhand

Contingency cropping of basmati rice (Pusa-1509) in 20 ha area resulted in a yield advantage of 1 q/ha over transplanted paddy in Killi Nihal Singh village, Bathinda, Punjab. Green manuring with *Sesbania* coupled with soil test based nutrient application was demonstrated in 39 ha covering 60 farmers at Badoushi Kalan village, Fatehgarh Sahib, Punjab.

Green manuring with Sesbania followed by Basmati paddy (Pusa-1509)

Contingency measures were implemented in paddy, pigeonpea and blackgram in Lowkeshra village in East Singhbhum, Jharkhand. In paddy, short duration and drought tolerant varieties (BVD-110 & Sahabaghi) were sown by direct seeding in uplands.

Drought tolerant variety Sahabagi dhan at East Singhbhum

Contingency cropping with Bajra demonstrated in rice fallows in 30 ha area covering 115 farmers gave an average yield of 29 q/ha with HHB-67 and 32 q/ha with VBH-24 cultivar in Kukurha village of Buxar, Bihar.

There was a total failure of maize and low yields in cotton (2.2 q/ac) due to severe drought. As a crop contingency measure, horse gram (var: CRHG 18R) was demonstrated in about 60 farmers fields by CRIDA in NICRA village. Horse gram sown during 18 Sept to 15 October yielded about 5 q grain and 5 q fodder per ha.

More than 460 climate resilient technologies viz., zero-tillage in wheat, direct seeded rice, bio- fertilizers, green manuring, raised bed and protected system for vegetables were taken up by IARI. A study with 63 rice growers and 162 wheat growers with the help of Village Climate Risk Management Committee, revealed that a majority of farmers adopted DSR (49%) and zero-tillage wheat (44%) in about 75-100% of their respective cropped area. Nearly 70% of the networked farmers in the adopted village switched over to DSR and zero till wheat technologies in at least 50% of thier respective crop area.

Direct Seeded Rice demonstration in Mumtajpur

A complete mechanization package of climate resilient practices in onion production was demonstrated in onion by IIHR, starting from sowing, harvesting and grading prior to marketing was demonstrated in the adopted villages.

Technology demonstrations in adopted cluster of villages in Meghalaya, Mizoram and Tripura was undertaken by ICAR-NEH. Zero till cultivation of pea was demonstrated in rice fallows. Adoption of raised and sunken bed technique permitted cultivation of other vegetable crops after rice. This technique protected the vegetable crop from excess moisture in the rice fields and gave additional returns from double cropping. Potato (Kufri Giriraj and Kufri Mega), Capsicum (Royal Wonder), Pea (Arkel), Tomato (Badshah) and French Bean (S-9) were cultivated in rice fallows during January to May. Net income from vegetable cultivation ranged from Rs.10000 to Rs.15000 from field sizes of 0.1 to 1.5 ha. Similarly in Mizoram, zero till short duration Pea (Rachana, 110 days duration)

along with mulching with crop residue was demonstrated in low land rice fallows in 40 ha area on residual soil moisture. The legume crop helped in improving soil nitrogen along with additional returns from the increased cropping intensity.

Technology demonstrations to address heat stress vulnerability and fodder scarcity in livestock in the adopted village cluster comprising of Manglora, Dilawara and Suhana villages in Karnal district were conducted by NDRI. A calendar in Hindi was made available to 300 farmers for advising appropriate livestock interventions and activities to be taken up in each month of the year. Two veterinary health camps were organized in Dilawara & Suhana villages and exposure visit of 100 famers to National Dairy Mela was organized in Feb 2015. Two awareness camps on safe dung disposal was conducted for 12 farmers and 24 farmers were trained on detection of heat symptoms in dairy animals.

Integrated farming system model at Datia in Madhya Pradesh

Demonstration of zero till Pea in rice fallows in Meghalaya and Mizoram

Livestock and Fisheries

In this module use of community land for fodder production, improved fodder/feed storage methods and improved shelter for reducing of heat stress in livestock were demonstrated.

Over 155 feeding trials were conducted to reduce mineral deficiency and increased milk productivity in milch animals under heat stress. About 684 fodder demonstrations were conducted to augment the availability of green fodder. Integrated farming system models were demonstrated at Datia, South 24 Parganas, Alleppey, Dhubri, Dimapur, East Sikkim, Imphal East and Sonitpur.

CMFRI developed a formulated feed for pearl spot and was launched by KVK, Ernakulam in the brand name of *'Pearl Plus'*.

Institutional Interventions

Small farm mechanisation through village level custom hiring centres managed by the village climate risk management committee (VCRMC) was promoted in all the 100 villages during 2014-15. Implements from the custom hiring center were hired by farmers for taking up timely sowing operations, practice water saving methods like direct seeding in paddy, in situ moisture conservation practices, zero tillage for advancement of planting dates of *rabi* crops in areas with terminal heat stress, and crop residue recycling. The most popular implements hired were: drum seeder, happy seeder, zero till drill, furrow irrigated ridger, multi crop planter. During 2014-15, revenue generated from top 5 performing custom hiring centres were Namakkal (Rs.1,03180), Ramanathpuram (Rs.54,900), Kota (Rs.54,200), West Tripura (Rs.43,360), Jhunjhunu (41,990) and Amravati (Rs.40,750). In 2014-15 revenue generated was Rs.7.94 lakhs and the cumulative revenue generated from 100 custom hiring centers stands at Rs.33.0 lakhs which is being used for repair, maintenance and training needs apart from apportioning towards sustainability fund at each center.

Capacity building

A number of capacity building training programmes for awareness and promotion of climate resilient practices and technologies were organized in all the 100 villages in different thematic areas such as natural resource management, crop production, livestock management and use of farm machinery.

Thematic area	No. of topics covered	No. of participants
NRM	118	4349
Resource conservation technologies	55	2225
Crop diversification	17	1063
Crop management	249	9562
Nutrient management	91	3438
Livestock management	139	5269

Participating Institutes

Additional Partner Institutes in XII Plan

1. Central Arid Zone Research Institute (CAZRI), Jodhpur
2. Central Institute of Freshwater Aquaculture, (CIFA), Bhubaneswar
3. Central Institute for Research on Goats(CIRG), Makhdoom
4. Central Institute of Temperate Horticulture (CITH), Srinagar
5. Central Potato Research Institute(CPRI), Shimla
6. Central Soil Salinity Research Institute (CSSRI), Karnal
7. Indian Institute of Soil and Water Conservation (IISWC), Dehradun
8. Central Sheep & Wool Research Institute (CSWRI), Avikanagar
9. Indian Institute of Maize Research (IIMR), New Delhi
10. Directorate of Onion & Garlic Research (DOGR), Pune
11. Directorate of Poultry Research (DPR), Hyderabad
12. Directorate of Soybean Research (DSR), Indore
13. Indian Institute of Wheat and Barley Research (IIWBR), Karnal
14. Indian Grassland and Fodder Research Institute (IGFRI), Jhansi
15. Indian Institute of Soil Science (IISS), Bhopal
16. National Bureau of Plant Genetic Resources (NBPGR), New Delhi
17. National Bureau of Soil Survey & Land Use Planning (NBSS&LUP), Nagpur
18. National Centre for Agricultural Economics & Poultry Research (NCAP), New Delhi
19. National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI), Bengaluru

Sponsored Grants Component

1. Punjab Agricultural University (PAU), Ludhiana
2. Central Soil Salinity Research Institute (CSSRI), Karnal
3. Central Institute for Cotton Research (CICR), Nagpur
4. Indian Institute of Sugarcane Research (IISR), Lucknow
5. Agri Biotech Foundation (ABF), Hyderabad
6. National Council for Climate Change, Sustainable Development and Public Leadership (NCCSD), Ahmedabad

NICRA

Research Highlights
2014-15

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