All India Coordinated Research Project on AGROMETEOROLOGY

भाकृअनुप
ICAR

Annual Report 2015 - 16

AICRPAM

CENTRAL RESEARCH INSTITUTE FOR DRYLAND AGRICULTURE 1985 केबाकृ अनुसं

All India Coordinated Research Project on Agrometeorology

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DIRECTOR

FOREWORD

Despite tremendous technological developments brought out by the Indian Council of Agricultural Research to enhance the food grain production of the country, the aberrations of weather are still playing havoc in threatening the food security of the country. Every year one or other part of this vast country are experiencing extreme weather events viz., drought, floods, abnormal temperatures, hail storms, cyclones etc. Moreover, with the increased frequency of extreme weather conditions in the back drop of climate change, the sustainability of agriculture production is at stake.

Under these circumstances, the All India Coordinated Research Project on Agrometeorology (AICRPAM) has a greater role to play in evolving long and short term measures for making agriculture more profitable. The AICRPAM through its network of 25 centres spread across the country is contributing in conducting research for identifying agroclimatologcally suitable areas for different crops, quantifying the impact of weather parameters and likely impact of climate change in future.

The efforts of the AICRPAM project over the years have culminated in establishing 100 Automatic Weather Stations (AWS) for monitoring real time weather conditions on a wider scale, developing website for informing about crop and weather conditions and issuing agromet advisory services to different clientele including farmers, researchers, planners etc. Efforts are afoot to reach more number of farmers through issue of agromet advisories at block level. Effective collaboration between AICRPAM and IMD is envisaged for improving the contents and outreach of agromet advisory services for minimizing climate risks in Agriculture. The Annual Progress report of 2015-16 comprises of the salient research results of the experiments conducted during *Kharif* 2015 and *Rabi* 2015-16 at all 25 centres of the project. I take this opportunity to congratulate the staff of all 25 centres and the former Project Coordinator, Dr. V.U.M. Rao and In-charge Project Coordinator, Dr. P.Vijaya Kumar and the team at the coordinating unit for bringing out this excellent report. I believe the information provided in the report will be useful for researchers, progressive farmers and policy makers for mitigating extremes of weather.

CH.SRINIVASA RAO

ICAR-CRIDA-Hyderabad
Date: November 21, 2016

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I sincerely express my gratitude to Indian Council of Agricultural Research for providing financial and administrative support to the project during the year 2015-16. The encouragement and guidance received from Dr. S. Ayyappan, Hon'ble Former Director General and Secretary (DARE) and Dr. A.K. Sikka, Former Deputy Director General (NRM) during the reporting period is highly acknowledged. The constant support and guidance being extended by Dr. Trilochan Mohapatra, Hon'ble Director General and Secretary (DARE), Dr. K. Alagusundaram, Acting Deputy Director General (NRM) and Dr. S. Bhaskar, Assistant Director General (AAF & CC) to the project is gratefully acknowledged. The help and guidance received from Dr. Ch. Srinivasa Rao, Director, CRIDA for the effective functioning of the project and also in preparing this report is acknowledged with sincere thanks.

I thank all the Agrometeorologists and staff of all 25 cooperating centres for successfully conducting the research programs for the year 2015-16 and also contributing the research results for the Annual Progress report. Dr. V.U.M. Rao, Former Coordinator deserves special thanks for making all the centres to submit the reports timely, through his constant monitoring.

I highly appreciate the efforts made by my colleagues Mr. M.A.SarathChandran, Mr. A.V.M.Subba Rao and Dr. B. Bapuji Rao for compilation of the report. I sincerely thank Mr. I.R.Khandgonda for providing technical support and Ms. D. Harini for type setting of the manuscript. The support provided by A. Mallesh Yadav is acknowledged with thanks. I also thank RA/SRFs Mr. V.P. Pramod, Mr. V.M. Sandeep, Mrs. Latha, Ms. O. Bhavani, Mr. V. Narsimha Rao and Mrs. K. Vijayalakshmi for their contribution to the report.

P. VIJAYA KUMAR

Incharge Project Coordinator (Ag.Met.)

1. Introduction

The All India Coordinated Research Project on Agrometeorology was initiated by ICAR in May 1983 with the establishment of Coordinating Cell at the Central Research Institute for Dryland Agriculture, Hyderabad and 12 Cooperating Centres at various State Agricultural Universities. After a detailed review and evaluation on the progress made by the project and realizing the importance of agrometeorological research support for enhancing food production, ICAR had extended the Cooperating Centres to the remaining 13 Agricultural Universities of the country w.e.f. April 1995. The 25 Cooperating Centres of the AICRPAM network are: Akola, Anantapur, Anand, Bangalore, Bhubaneswar, Bijapur, Dapoli, Faizabad, Hisar, Jabalpur, Jorhat, Kanpur, Kovilpatti, Ludhiana, Mohanpur, Palampur, Parbhani, Raipur, Rakh Dhiansar (Chatha/Jammu), Ranchi, Ranichauri, Samastipur, Solapur, Thrissur and Udaipur. The Quinquennial Review Team has reviewed the research progress of the project in 1992, 1998-99, 2006 and 2011. In the latest QRT Report performance of the AICRPAM was adjudged as **VeryGood**.

1.1 Objectives

- To study the agricultural climate in relation to crop planning and assessment of crop production potentials in different agroclimatic regions
- To establish crop-weather relationships for all the major rainfed and irrigated crops in different agroclimatic regions
- To evaluate different techniques of modification of crop micro-climate for improving the water use efficiency and productivity of the crops
- To study the influence of weather on the incidence and spread of pests and diseases of field crops

1.2 Technical Program for 2014-16

The Technical Program for the years 2014-16 for different centres of the project and a common core program decided for all the centres with emphasis on location-specific research needs is given below.

1) Agroclimatic Characterization (All centres)

Development of database (Block, Tehsil or Mandal level) on climate and crop statistics (district level)

Agroclimatic Analysis

- Rainfall probability analysis
- Dry and wet spells
- Effective rainfall, water balance studies (FAO-CROPWAT) and harvestable rainwater for every week
- Characterization of onset of monsoon for crop planning
- Climatic and agricultural drought analysis
- Length of growing season and its variability

- Preparation of crop-weather calendars
- Consolidation of agroclimatic analysis in the form of Technical Reports and Agroclimatic Atlases
- Preparation of crop-wise manuals for weather-based decisions in crop management.
- Documentation of extreme weather events and their impacts on agriculture including on livestock, poultry and fish (During the reporting year)

2) Crop-Weather Relationships (All Centres)

Centre	Kharif Crop(s)	Rabi Crop(s)
Akola	Soybean	Chickpea
Anand	Groundnut	Wheat
Anantapur	Groundnut	Chickpea (Nandyal)
Bangalore	Pigeonpea	Mango
Vijayapura	Pigeonpea	Soybean
Bhubaneswar	Rice	——
Chatha/Jammu	Maize	Wheat
Dapoli	Rice	Mango
Faizabad	Rice	Chickpea, Mustard
Hisar	Cluster bean/Horticulture	Mustard, Wheat
Jabalpur	Soybean	Chickpea
Jorhat	Rice	Potato
Kanpur	Rice	Wheat
Kovilpatti	—	Greengram, Maize
Ludhiana	Rice	Wheat
Mohanpur	Rice	Potato
Palampur	Tea	Wheat
Parbhani	Cotton, Soybean	——
Raipur	Rice	Wheat
Ranchi	Rice	Wheat
Ranichauri	Finger millet	Wheat
Samastipur	Rice	Wheat, Winter Maize
Solapur	Pearlmillet	Sorghum
Thrissur	Coconut, Rice	Pepper
Udaipur	Maize	Wheat

3) Crop Growth Modelling

Crop	Lead Centre	Associated Centres
Wheat	Ludhiana	Palampur, Anand, Jabalpur, Chatha/Jammu, Samastipur, Ranchi, Hisar, Kanpur, Ranichauri
Rice	CRIDA	Mohanpur, Samastipur, Dapoli, Faizabad, Thrissur, Bhubaneswar, Jorhat, Ranchi, Kanpur, Jabalpur, Raipur
Groundnut	Anand	Anantapur, Bangalore

4) Weather Effects on Pests and Diseases

Centre	Crop(s)	Pests/diseases
Anand	Mustard	Aphids
Anantapur	Groundnut	Leaf miner
Akola	Soybean	Spodoptera/Semilooper
Bangalore	Groundnut, Redgram	late leaf spot, Heliothis
Vijayapura	Grapes, Pomegranate	Powdery mildew, Downy mildew Anthracnose, Bacterial Leaf Blight
Bhubaneswar	Rice	Sheath Blight, Blast
Chatha/Jammu	Wheat	Yellow rust
Faizabad	Chickpea	Pod borer
Jabalpur	Chickpea	Heliothis
Kovilpatti	Cotton, Blackgram	Aphids, Leaf hopper, Powdery mildew
Ludhiana	Cotton	Sucking pests
Mohanpur	Mustard, Potato	Aphids, Late blight
Palampur	Mustard, Wheat	Aphids, Yellow rust
Parbhani	Cotton	Mealy bug, sucking pests
Ranchi	Rice	BLB, Brown spot
Ranichauri	Apple, Amaranthus	Apple scab, Leaf webber
Solapur	Sunflower	Leaf eating caterpillar (Heliothis)
Raipur	Rice, Chickpea	Stemborer, Leaf blast/Brown spot, Heliothis
Kanpur	Rice, Wheat	Blight, Stem borer, Blight
Thrissur	Rice	Stemborer, Leaf roller
Udaipur	Mustard	Aphids
Hisar	Mustard, Wheat	Aphid, Yellow rust

5) Agromet Advisory Services (All Centres)

- Monitoring of crop and weather situation, twice in a week and its updating on the website
- Development of contingency plans for aberrant weather situation
- Monitoring of extreme weather events and their impacts on farming systems on near real-time basis
- Value-addition to agromet information
- Economic impact assessment

2. Weather Conditions During the Year 2015

A brief account of onset, withdrawal and rainfall details of southwest monsoon as well as post monsoon seasons of the year 2015 for the country as a whole and annual rainfall at 25 centres of AICRPAM are presented hereunder:

Onset of southwest monsoon (June – September):

The southwest monsoon (SW) set in over Kerala on 5th June, 4 days later than its normal date (1st June). Associated with this event, monsoon advanced into entire south Arabian Sea, some parts of central Arabian Sea, entire Lakshadweep area, some parts of coastal & south interior Karnataka and Tamil Nadu, most parts of south Bay of Bengal, some more parts of west central Bay of Bengal and some parts of northeast Bay of Bengal. By 14th June monsoon covered central Arabian Sea, some parts of north Arabian Sea, entire south Peninsula, and most parts of central and northeast India. The formation of couple of intense low pressure systems, one each in Arabian Sea (Deep Depression) and in Bay of Bengal (Depression) towards the end of third week helped rapid advance of monsoon covering the entire country by 26th June.

Rainfall distribution during monsoon season

The seasonal (June to September) rainfall received at 36 meteorological sub-divisions of the country during the 2015 SW monsoon season are given in the Table 2.1 along with respective long period average (LPA) values and deviations from normal.

Table 2.1: Rainfall at 36 meteorological sub-divisions during monsoon season (June – September) – 2015

S. No.	Meteorological sub division	Actual (mm)	Normal (mm)	Excess or deficit (mm)	Deviation (%)
1	Andaman & Nicobar Islands	1679	1683	-4	0
2	Arunachal Pradesh	1875	1768	107	6
3	Assam & Meghalaya	1748	1793	-45	-3
4	Nagaland, Manipur, Mizoram, Tripura	1050	1497	-447	-30
5	Sub-Himalayan West Bengal & Sikkim	1883	2006	-123	-6
6	Gangetic West Bengal	1266	1168	98	8
7	Odisha	1034	1150	-116	-10
8	Jharkhand	942	1092	-150	-14
9	Bihar	742	1028	-285	-28
10	East Uttar Pradesh	472	898	-426	-47
11	West Uttar Pradesh	440	769	-330	-43
12	Uttarakhand	882	1229	-348	-28

13	Haryana, Chandigarh & Delhi	296	466	-171	-37
14	Punjab	336	492	-156	-32
15	Himachal Pradesh	838	825	13	2
16	Jammu & Kashmir	614	535	79	15
17	West Rajasthan	384	263	121	46
18	East Rajasthan	557	616	-59	-10
19	West Madhya Pradesh	915	876	38	4
20	East Madhya Pradesh	745	1051	-306	-29
21	Gujarat Region	659	901	-242	-27
22	Saurashtra, Kutch & Diu	503	474	29	6
23	Konkan & Goa	2005	2914	-909	-31
24	Madhya Maharashtra	488	729	-241	-33
25	Marathwada	412	683	-271	-40
26	Vidarbha	848	955	-106	-11
27	Chhattisgarh	1010	1147	-138	-12
28	Coastal Andhra Pradesh	642	581	61	10
29	Telangana	601	755	-154	-20
30	Rayalaseema	358	398	-40	-10
31	Tamil Nadu & Pondicherry	286	317	-31	-10
32	Coastal Karnataka	2285	3084	-799	-26
33	North Interior Karnataka	357	506	-149	-29
34	South Interior Karnataka	607	660	-53	-8
35	Kerala	1515	2040	-525	-26
36	Lakshadweep	861	999	-138	-14

The rainfall during southwest monsoon season from 1st June to 30th September 2015, was normal in 18 subdivisions (55% of the total area of the country) and deficient in 17 sub-divisions (39% of the total area of the country). Only one sub-division (West Rajasthan) constituting 6% of the total area of the country received excess rainfall. Out of the 17 deficient sub-divisions, 6 sub-divisions were from northwest India, 5 from central India, 2 from northeast India and 4 from south Peninsula.

Monthly distribution of rainfall: In June, except 3 sub-divisions (Bihar, sub division comprising Nagaland, Manipur, Mizoram & Tripura, and Andaman & Nicobar Islands), which received deficient rainfall, all the other sub-divisions (34 out of 36) received normal (20 sub-divisions) or excess (13 sub-divisions) rainfall.

In July, majority of the sub-divisions from Peninsular India and that from north India along the Himalayas received deficient or scanty rainfall. In total, 19 sub-divisions received deficient rainfall, 4 sub-divisions received scanty rainfall and 6 sub-divisions received normal rainfall. The remaining 7 sub-divisions (3 from northwest India and 2 each from central and east India) received excess rainfall. The scanty rainfall sub-divisions were: Marathwada, North Interior Karnataka, Telangana and Rayalaseema.

In August, majority of the sub-divisions from northwest India, central India and neighboring Peninsula received deficient/ scanty rainfall. On the other hand, majority of the sub-divisions from northeast India received normal/ excess rainfall. During August, 3 sub-divisions received excess rainfall, 10 sub-divisions received normal rainfall, 20 sub-divisions received deficient and 3 sub-divisions received scanty rainfall. The excess sub-divisions were Sub Himalayan West Bengal & Sikkim, Assam and Meghalaya, and Arunachal Pradesh and the sub-divisions that received scanty rainfall were: Saurashtra, Kutch, Gujarat and Madhya Maharashtra.

In September, majority of the sub-divisions from northwest India, west central India and east India received deficient/ scanty rainfall. On the other hand, majority of the sub-divisions from south Peninsula and neighboring central India, and northeast India received normal/ excess rainfall. During September, 4 sub-divisions received excess rainfall, 18 sub-divisions received normal rainfall, 6 sub-divisions received deficient and 8 sub-divisions received scanty rainfall. The sub-divisions which received excess rainfall were: Jammu and Kashmir, Saurashtra and Kutch, Kerala and Andaman & Nicobar Islands.

From the monthly distribution, it can be seen that all the sub-divisions have received deficient/ scanty monthly rainfall during at least one of the four months. However, none of the sub-divisions were deficient/ scanty during all the four months of the season. Except in June, during each of the other 3 months, at least 14 out of the 36 sub-divisions had received deficient/ scanty rainfall. During the peak rainfall months of July and August, 23 sub-divisions each had received deficient/scanty rainfall. Saurashtra and Kutch received scanty rainfall during August but received excess rainfall during all the other 3 months.

Withdrawal of southwest monsoon

Withdrawal of southwest monsoon from the northwestern parts of Rajasthan commenced on 4th September. Monsoon withdrew from some more parts of Rajasthan and some parts of Punjab and Haryana on 9th September. On 29th September, monsoon withdrew from remaining parts of Rajasthan, Punjab, Haryana, Chandigarh & Delhi, entire Jammu & Kashmir, Himachal Pradesh, Uttarakhand, most parts of West Uttar Pradesh and some parts of West Madhya Pradesh, Gujarat State and north Arabian Sea. On 6th October, the monsoon further withdrew from some more parts of Bihar; remaining parts of Madhya Pradesh; some parts of Jharkhand, Chhattisgarh, Vidarbha, Madhya Maharashtra; some more parts of Gujarat state and north Arabian sea. On 15th October, southwest monsoon further withdrew from some more parts of Jharkhand, most parts of Chhattisgarh, remaining parts of Vidarbha, Madhya Maharashtra, Gujarat State and north Arabian Sea, entire Marathwada and Konkan & Goa and some parts of Odisha, Telangana, North Interior Karnataka and central Arabian Sea. Withdrawal of southwest monsoon from the entire country was on 19th October.

Post-monsoon (October- December) 2015

In the sub division-wise Post- Monsoon (October – December) season rainfall, it was noticed that rainfall was excess in 5 sub-divisions viz., Jammu & Kashmir, Rayalaseema, Tamil Nadu & Pondicherry, Kerala and Lakshadweep, normal in 5 sub-divisions viz., Andaman & Nicobar Islands, Konkan & Goa, Coastal Andhra Pradesh, Coastal Karnataka and South Interior Karnataka, deficient in 8 sub-divisions viz., 3-sub divisions comprising all North eastern states, Sub Himalayan West Bengal, Himachal Pradesh, East Madhya Pradesh, Madhya Maharashtra and North interior Karnataka and scanty in remaining 18 sub-divisions.

Rainfall situation at cooperating centers

During the year 2015, 4 out of 25 centers of the All India Coordinated Research Project on Agrometeorology, viz., Anantapur, Chatha (Jammu), Hisar and Kovilpatti received excess rainfall, 11 centers viz., Akola, Bangalore, Vijayapura, Jorhat, Jabalpur, Ludhiana, Mohanpur, Palampur, Ranichauri, Thrissur and Udaipur received normal rainfall and remaining 10 centers received either deficit or scanty rainfall (Table 2.2).

Table 2.2: Annual Rainfall received at AICRPAM centers during 2015

S. No.	Centre	Actual (mm)	Normal (mm)	Departure (%)
1	Akola	797	813	-2
2	Anand	539	853	-37
3	Anantapur	641	432	48
4	Bangalore	1071	917	17
5	Bhubaneshwar	1031	1502	-31
6	Vijayapura	651	594	10
7	Chatha/Jammu	1532	1124	36
8	Dapoli	2331	3529	-34
9	Faizabad	642	1001	-36
10	Hisar	639	452	41
11	Jabalpur	1201	1395	-14
12	Jorhat	2000	1822	10
13	Kanpur	627	898	-30
14	Kovilpatti	989	723	37
15	Ludhiana	737	733	1
16	Mohanpur	1451	1607	-10
17	Palampur	2652	2320	14
18	Parbhani	575	963	-40

19	Raipur	1041	1399	-26
20	Ranchi	925	1270	-27
21	Ranichauri	1081	1270	-15
22	Samastipur	947	1235	-23
23	Solapur	481	721	-33
24	Thrissur	2634	2782	-5
25	Udaipur	601	566	6

3. Agroclimatic Characterization

Characterization of crop growing environment is a pre-requisite for crop planning and evolving strategies to overcome climate /weather induced changes in the meso / micro climate. Anomalies in climatic variables need to be properly understood to make agricultural sector resilient to climate change. Thus, historic data on climatic variables have to be analyzed using appropriate statistical tools for the development of location specific technologies / adaptive strategies. The analysis carried out by different centers on the agroclimatic characterization is reported hereunder:

Anand

Length of Growing Period (LGP) for different parts of Gujarat state was estimated using two methods, viz., Thornthwaite and Mather's bookkeeping method (1957) and FAO (1978) method. Climatic data of 17 stations, geographically distributed over the whole state was used to determine LGP of different parts of Gujarat state. The computations were made after pre-processing of data using Weather Cock software (CRIDA, 2011). Weekly rainfall and estimated PET were used to calculate Moisture Adequacy Index (MAI) using weekly water balance method for soils of different water holding capacities viz., 50, 100, 150 and 200 mm in root zone. It was assumed that the season starts in a week after the 22^{nd} standard meteorological week (SMW), if the MAI value of two consecutive weeks is ≥ 0.5, and it ends if MAI is ≤ 0.25 for three consecutive weeks after 40^{th} SMW. The station-wise output was spatially interpolated by krigging in SAGA GIS for mapping of the length of growing season for the whole state and the results are presented in Fig. 3.1

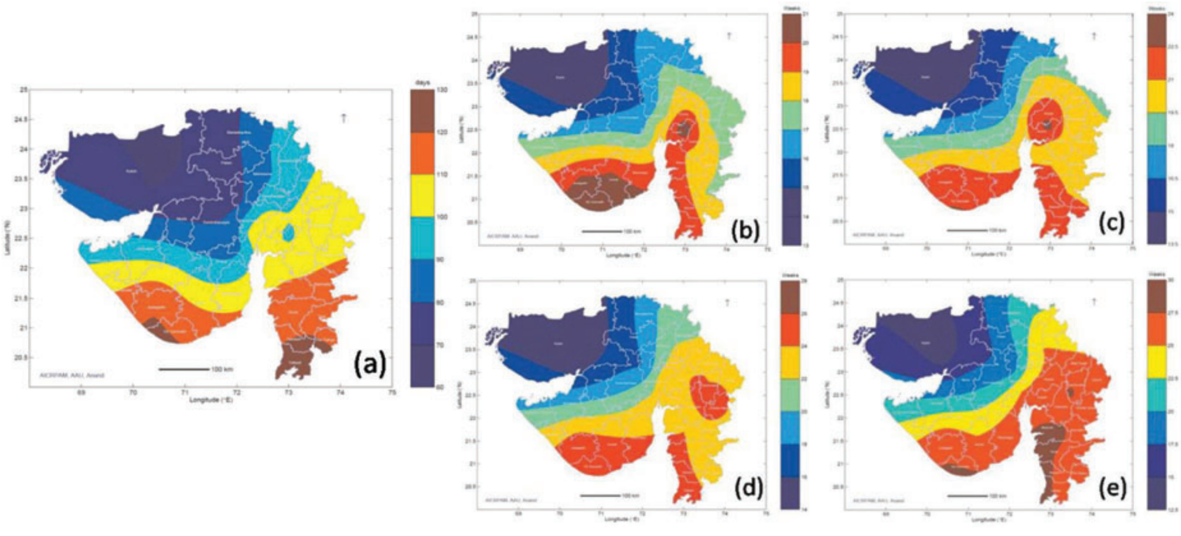


Fig. 3.1: Length of Growing Period (LGP) estimated over different parts of Gujarat (a) using FAO water balance method; using Thornthwaite book keeping method for soil water holding capacities viz., (b) 50 mm, (c) 100 mm, (d) 150 mm and (e) 200 mm

Length of growing period ranged from 120-130 days in south Gujarat to 60-80 days in north-western parts of Gujarat state. Valsad, parts of Gir Somnath, Surat and Dangs districts have maximum LGP of 120-130 days. Kutch district and part of north Gujarat region showed minimum LGP (< 80 days). The growing period terminate early in Kutch district and remain active for longer period in south Gujarat, parts of south Saurashtra and parts of north Gujarat.

Akola

Trend analysis of monsoon (June–September) rainfall for different rainfall spells was undertaken using long term (1971-2015) daily rainfall data of selected locations across the districts of Vidarbha region.The Mann-Kendall test using trend/change detection software was performed to evaluate the trend of different rainfall spells (< 2.5 mm for 10 days duration, ≥ 10 mm for 7 days duration and ≥ 25 mm for 3 days) in these locations. The summary of the results are presented in Tables 3.1 and 3.2.

Table 3.1 Trend statistics of longest rainfall spell under different intensity classes at selected locations in the districts of Vidarbha (Data period: 1971-2015)

Station	Mann Kendall test statistics		
	Longest spell (< 2.5 mm)	Longest spell (≥ 10 mm)	Longest spell (≥ 25 mm)
Akola	-0.127 (NS)	-2.221 (Sig 0.05)	-0.675 (NS)
Amravati	+1.125 (NS)	+0.254 (NS)	-0.117 (NS)
Buldana	-0.342 (NS)	+0.841 (NS)	+0.518 (NS)
Washim	-1.233 (NS)	-0.959 (NS)	-0.607 (NS)
Yavatmal	+1.115 (NS)	-0.166 (NS)	+1.115 (NS)
Wardha	+0.470 (NS)	-0.020 (NS)	-0.088 (NS)
Nagpur	-2.563 (Sig 0.05)	+1.565 (NS)	+0.225 (NS)
Sakoli	+0.119 (NS)	0.000 (NS)	-1.245 (NS)
Chandrapur	-1.993 (Sig 0.05)	-1.173 (NS)	+1.113 (NS)
Sindewahi	-1.008 (NS)	+0.147 (NS)	+0.137 (NS)
Sironcha	-0.734 (NS)	-0.421 (NS)	+0.196 (NS)

NS-Non Significant, Sig 0.05-Significant at 95% level

Longest spell of consecutive non-rainy days, i.e. consecutive days with < 2.5mm rainfall during southwest monsoon showed significant decreasing trend at Nagpur and Chandrapur. Longest spell of consecutive days with ≥ 10 mm rainfall showed significant decreasing trend at Akola. For the longest spell of consecutive days with ≥ 25mmrainfall, no location showed any significant trend.

Table 3.2: Trend statistics of total number of spells under different intensity classes in selected location in the districts of Vidarbha

Station	Mann Kendall test statistics				
	Total spell (< 2.5 mm for 10 days)	Total spell (≥ 10 mm for 7 days)	Total spell (≥ 25 mm for 3 days)	Total spell (≥ 50 mm for 2 days)	Total spell (≥ 100 mm for 1 day)
Akola	-1.565 (NS)	-0.186 (NS)	-0.773 (NS)	-0.988 (NS)	-1.008 (NS)
Amravati	-0.372 (NS)	##	-1.086 (NS)	+0.147 (NS)	+0.049 (NS)
Buldana	-2.543 (Sig 0.05)	+0.401 (NS)	+1.076 (NS)	+0.333 (NS)	+2.553 (Sig 0.05)
Washim	-1.056 (NS)	+0.166 (NS)	+0.284 (NS)	+0.714 (NS)	+0.548 (NS)
Yavatmal	-0.137 (NS)	-0.186 (NS)	+0.880 (NS)	-0.401 (NS)	0.000 (NS)
Wardha	-0.900 (NS)	##	+0.166 (NS)	+0.910 (NS)	+0.470 (NS)
Nagpur	-1.272 (NS)	##	+0.734 (NS)	+1.790 (Sig 0.1)	+1.350 (NS)
Sakoli	+1.008 (NS)	-0.237 (NS)	-0.771 (NS)	-0.904 (NS)	+0.326 (NS)
Chandrapur	-1.072 (NS)	+0.394 (NS)	+0.688 (NS)	+0.819 (NS)	+1.416 (NS)
Sindewahi	-1.008 (NS)	+0.205 (NS)	-0.587 (NS)	+0.059 (NS)	+0.548 (NS)
Sironcha	-0.039 (NS)	+0.675 (NS)	-0.274 (NS)	-0.841 (NS)	+0.470 (NS)

indicates no spell of respective category, NS-Non Significant, Sig 0.05-Significant at 95% level, Sig 0.1-Significant at 90% level

Regarding the number of spells of 10 days duration with <2.5 mm rainfall, only Buldana showed significant decreasing trend. As far as total spells of ≥ 10 mm rainfall for 7 days and ≥ 25 mm rainfall for 3 days are concerned, none of the stations showed either increasing or decreasing trend significantly. For total number of spells of ≥ 50 mm rainfall for 2 days,only Nagpur showed significant increasing trend. With regard to the total spells of ≥ 100 mm for 1 day, only Buldana showed significant increasing trend.

Anantapur

To understand the effect of El Niño years on monthly, seasonal and annual rainfall, monthly as well as annual rainfall data of Anantapur district during 1991-2014 was analyzed. Monthly and annual rainfall during strong, moderate and weak El niño years were separately averaged and compared with the long term average of respective month, season and annual rainfall (Table 3.3).

Table 3.3 Monthly rainfall (mm) situation in Anantapur district during El Niño and normal years (1991-2014)

		Years under El Niño intensity categories										
		Strong				Moderate				Weak		
Month	Normal RF (mm)	1991	1997	2009	Mean	1994	2002	2014	Mean	2004	2006	Mean
January	1.6	2	3.9	0.5	2.1	11.6	6.6	0	6.1	1.3	0	0.65
February	1.3	0	0	0	0.0	0.1	1.5	0	0.5	0	0	0
March	3.3	1.7	12.3	6.8	6.9	0	0.1	18.2	6.1	11.4	40.7	26.05
April	12.8	24.2	6.8	4.7	11.9	16.9	17.2	12.9	15.7	32.7	11.8	22.25
May	39.6	54.2	6.6	71.4	44.1	35.4	83.2	57.4	58.7	125.2	59.4	92.3
June	63.9	119.2	70.8	55.4	81.8	19.4	38.4	44.9	34.2	18.2	79.1	48.65
July	67.4	16.6	10.6	8.9	12.0	42.2	21.1	35.7	33.0	108.4	21	64.7
August	88.7	25.7	65.5	102.9	64.7	29.6	37.9	56.8	41.4	14.8	15.6	15.2
September	118.4	80.9	170.5	191.3	147.6	27.3	59.5	35	40.6	106.6	85.7	96.15
October	110.7	128.7	46.8	61.2	78.9	169	104.9	84.9	119.6	69.2	45.6	57.4
November	34.7	49.4	49.2	67.2	55.3	16.4	13.3	11.7	13.8	10.4	73.8	42.1
December	9.9	0	26	4	10.0	0.1	1	4.1	1.7	0	0.9	0.45
Annual	552.3	502.6	469	574.3	515.3	368	384.7	361.6	371.4*	498.2	433.6	465.9

**Observation is significant at P=0.05*

The analysis indicated that negative impact of El Niño on annual and southwest monsoon rainfall was greatest during moderate El Niño years (1994, 2002 and 2014). On an average, 32% reduction in annual rainfall was observed during moderate El Niño years, compared to the normal annual rainfall of 552 mm, which is statistically significant at P=0.05. During southwest monsoon period (June – September), July month recorded 82% deficit rainfall during strong El Niño years, while August received 83% deficit rainfall during weak El Niño years. During moderate El Niño years, June, July, August and September received 46%, 51%, 53% and 65% deficit rainfall, respectively, which might have contributed to the highest annual deficit among different intensity classes of El Niño years.

Bangalore

Trends in rainfall and rainy days of both annual and southwest monsoon season were worked out using rainfall data of 392 rain gauge stations in Karnataka. The results presented in Figures 3.2 and 3.3 brought out that 82 percent of the stations in the state had no significant trend in annual rainfall. Among the remaining stations of the state, 13% showed positive trend, and 6% showed negative trend. Out of the stations with positive trend, 50% showed significance at P-level 0.1, 28% showed significance at P-level 0.05 and 22% stations showed significance at one percent P-level. Out of the stations with negative trend, 38% showed significance at 10% P-level, 48 percent of stations showed significance at 5% P-level and 14 percent of stations showed significance at 1% P-level. Thus, the negative trend observed is significant at more number of stations. Amongst the districts, all stations in Hassan and Haveri districts (6 each) showed positive trend. In Chamarajanagara and Kodagu districts, four out of the five stations showed positive trend, whereas it was reverse in Vijayapura district (4 out of five stations showed negative trend) and Tumakuru district (3 out of four showed negative trend). On the other hand, trend at all the three stations was negative in Dharwad and Raichur districts.

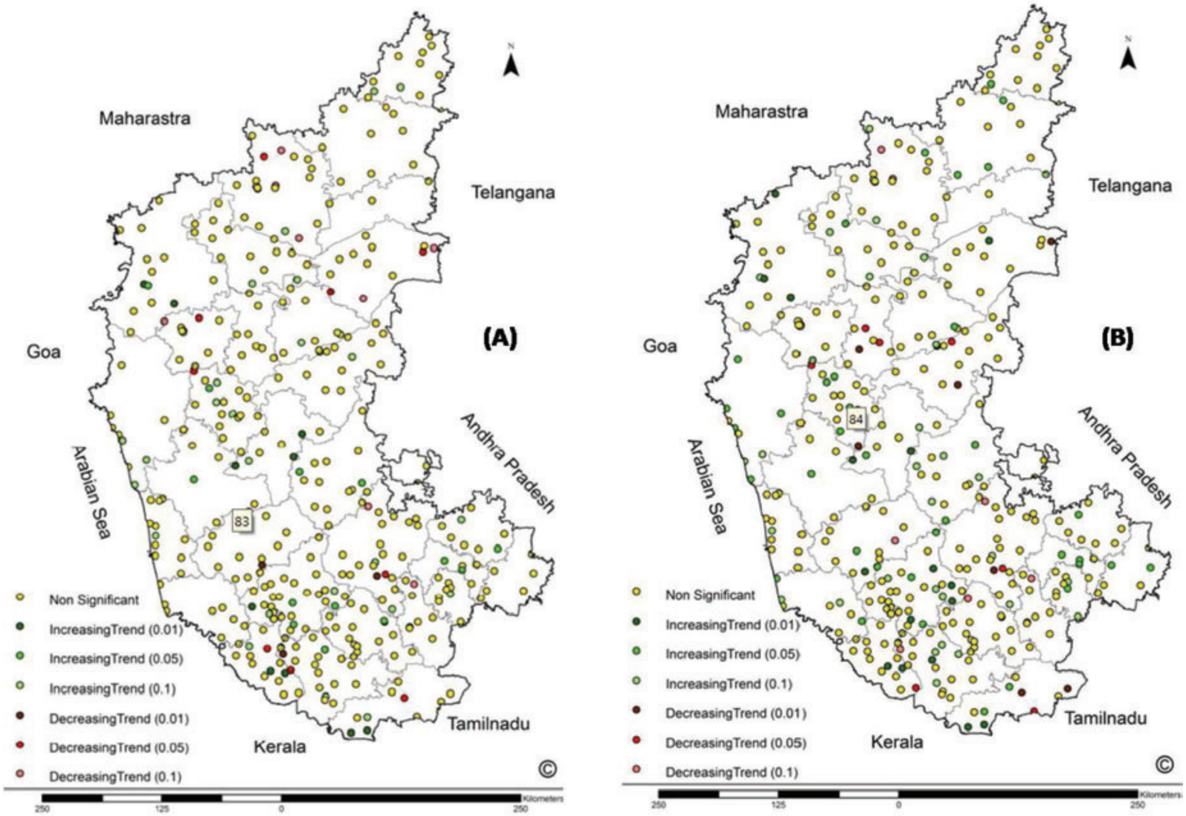


Fig. 3.2 Trend statistics of annual rainfall (A) and annual rainy days (B) at 392 locations of Karnataka

Regarding annual rainy days, 71 percent of the stations in the state showed no significant trend, 23% of stations showed positive trend and 6% showed negative trend (Fig. 3.2 (B)). Out of the stations with positive trend, 38%, 44% and 18% showed significance at P-levels10, 5 and 1 percent, respectively. Among the districts, all stations in districts Hassan (12), Haveri (6) and Uttara Kannada (7) showed positive trend in rainy days. In Chamarajanagara (five out of eight), Mysuru (6 out of 7) and Davanagere (4 out of 5) showed positive trend, whereas in Vijayapura district, stations with both negative and positive trends were same (3 out of 6).

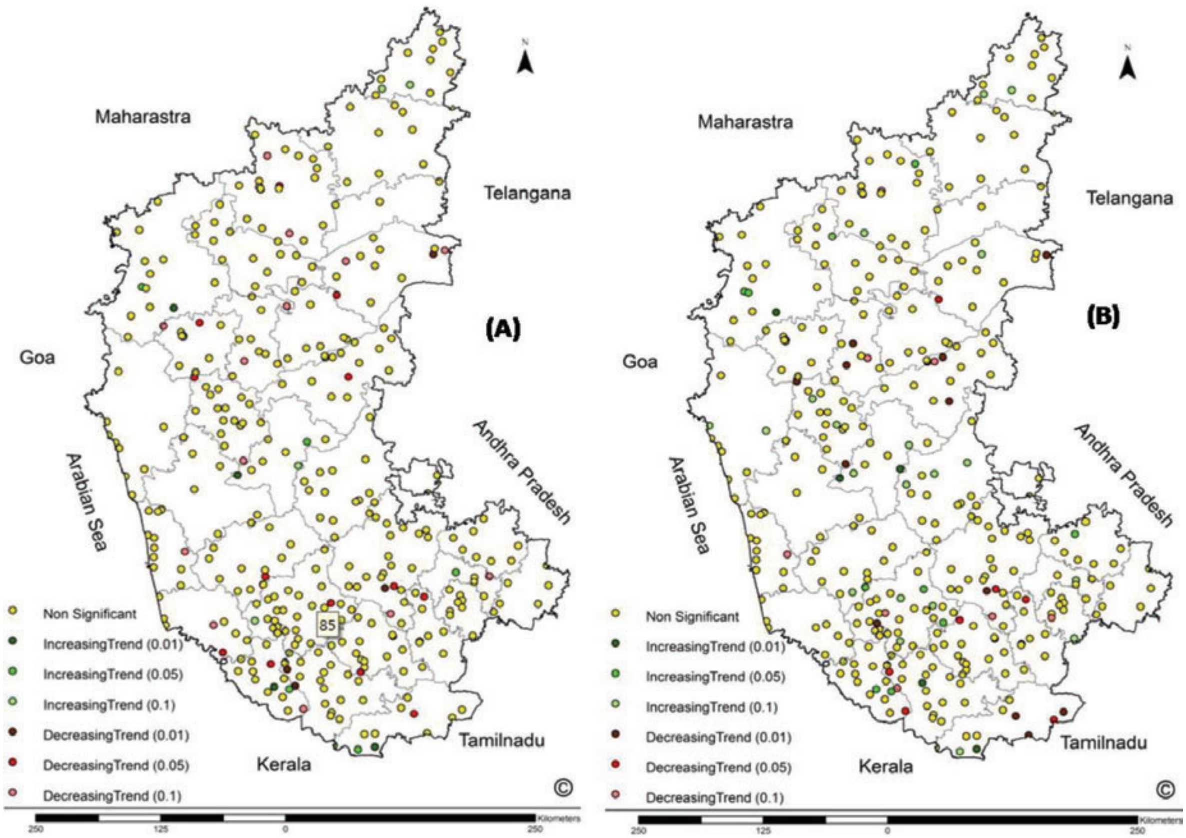


Fig. 3.3 Trend statistics of southwest monsoon rainfall (A) and rainy days during southwest monsoon (B) in 392 locations of Karnataka

During southwest monsoon season, 88 percent of stations did not show any trend in rainfall. Out of the remaining 12% of the stations, 4 and 8% of stations showed positive and negative trends, respectively [Fig. 3.3 (A)]. In Kodagu district, three out of five stations showed positive trend, whereas in Davanagere and Chamarajanagara 3 out of 4 stations showed positive trend. On the other hand, in Vijayapura district, all the four stations showed negative trends in rainfall. In case of rainy days, 83 percent of stations did not show any trend, 9% stations showed positive trend and 7% stations showed negative trend [Fig. 3.3 (B)]. In Ballari and Haveri, 2 out of 5 stations showed positive trend, whereas in Mysuru 3 out of 7 stations and in Kodagu 3 out of 4 stations showed positive trend.

Bhubaneswar

Trend analysis of annual rainfall and rainy days in 30 districts of Odisha was conducted using daily rainfall data for the period 1991-2014 and the results are presented in Fig. 3.4 (A). Six out of 30 districts showed increasing trend in annual rainfall. The increasing trend was significant at P=0.01 for Nawarangpur district, P=0.05 for Gajapati and Sambalpur districts and P=0.1 for Keonjahr, Nuapada and Rayagada districts.

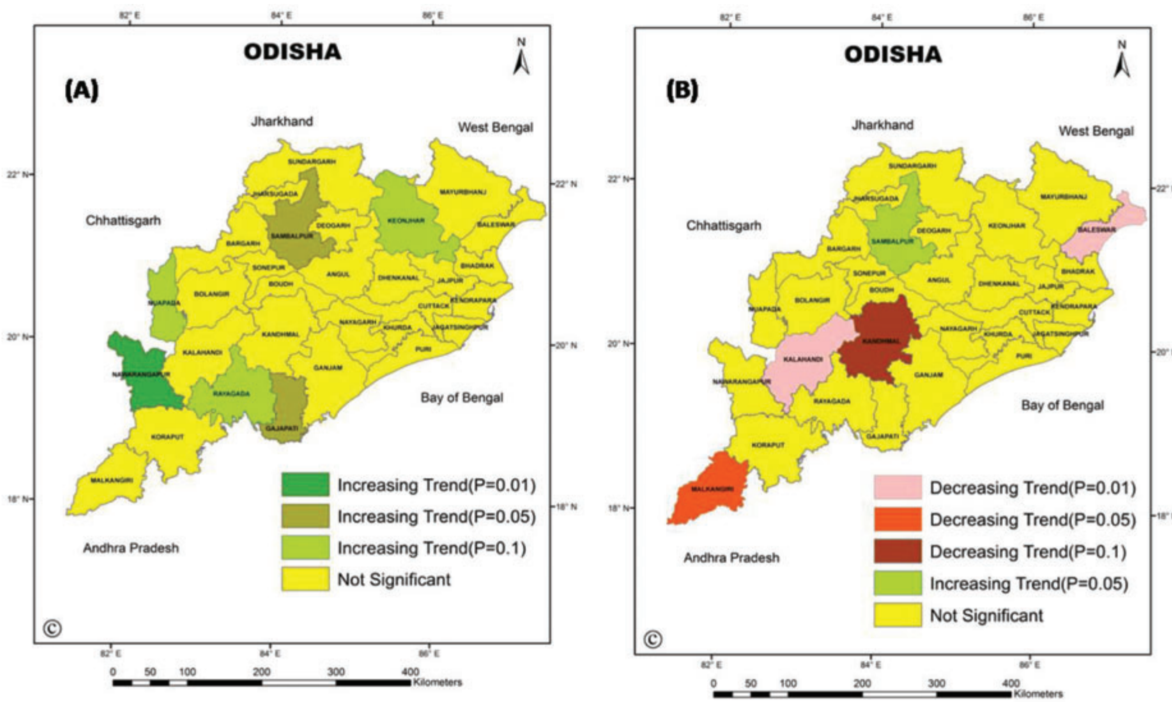


Fig. 3.4 Trend in annual rainfall in districts of Odisha during 1991-2014

Results of trend analysis in annual rainy days are presented in Fig. 3.4 (B). Sambalpur district showed increasing trend at P=0.05. Balasore and Kalahandi districts showed decreasing trend at P=0.01, Malkangiri at P=0.05 and Kandhamal at P=0.1.

Vijayapura

Demarcation of productivity zones for paddy, sorghum, finger millet and pigeon pea in Karnataka state was undertaken. According to this analysis, the districts were placed in nine different categories depending on the area and productivity levels. The nine categories considered are: High area-High yield (HH), High area - Medium yield (HM), High area - Low yield (HL), Medium area-High yield (MH), Medium area-Medium yield (MM), Medium area-Low yield (ML), Low area-High yield (LH), Low area - Medium yield (LM) and Low area - Low yield (LL). Depending upon the availability of water resources, management strategies are needed to be evolved to bridge the gap in yield levels. The results for paddy, sorghum, finger millet and pigeon pea crops are presented in Fig 3.5 A, B, C and D.

In case of paddy, there is scope for improvement of productivity in Bidar and Dharwad districts. The area under sorghum is dominant in six districts of north Karnataka (Belagavi, Vijayapura, Bagalkot, Kalaburagi, Yadgir and Raichur) districts, where there is scope for further improvement in productivity. The sorghum productivity needs considerable improvement in Gadag, Dharwad and Koppal districts, where the productivity level is low. Finger millet crop (Ragi) is mainly grown in southern parts of Karnataka. The crop can have

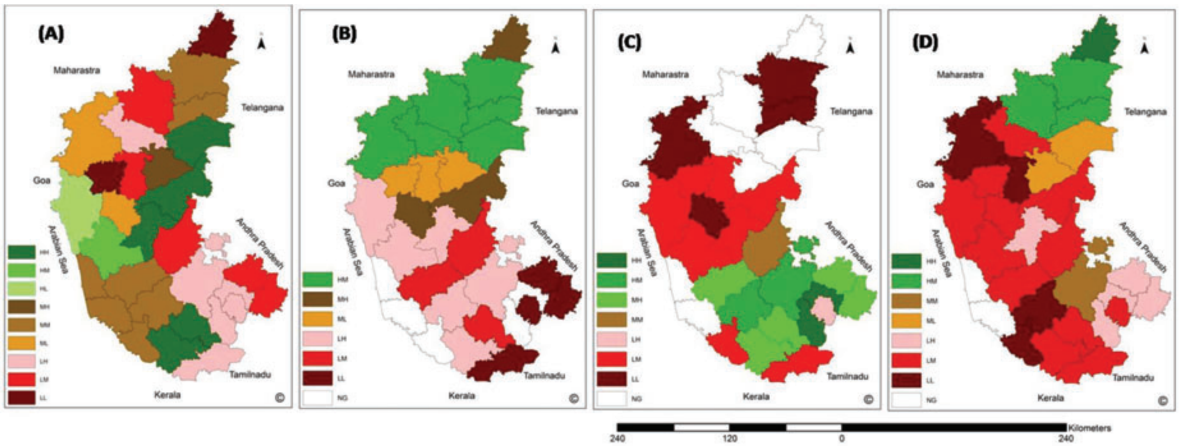


Fig. 3.5 Delineation of different productivity zones for (A) Paddy (B) Sorghum (C) Finger millet and (D) Pigeon pea for Karnataka.

enhanced productivity in Tumakuru and Hassan districts by adoption of improved technologies including varieties, whereas in Kolar, Chikkaballapur and Chikkamagaluru districts, more area can be brought under ragi as productivity is high. In north Karnataka there is scope for improvement in productivity of pigeonpea in Kalaburagi, Vijayapura and Yadgir districts, whereas in Raichur and Koppal districts it is essential to adopt better technologies and improve the productivity.

Faizabad

Analysis of dryspells during southwest monsoon period was undertaken using daily rainfall data for the period 1990-2015. A dry spell was defined as minimum ten continuous days with rainfall less than 2.5 mm. Year-wise longest dry spell, total number of events and total number of days with less than 2.5 mm rainfall during southwest monsoon were worked out and the results are presented in Table 3.4.

Table 3.4 Dry spell analysis during southwest monsoon period (1990-2015) at Faizabad

Year	Longest spell (Days)	Total number of spells	Total days with rain < 2.5 mm	Year	Longest spell (Days)	Total number of spells	Total days with rain < 2.5 mm
1990	23	2	83	2003	8	0	79
1991	18	3	88	2004	13	2	86
1992	13	3	92	2005	14	2	79
1993	17	1	87	2006	24	2	94
1994	10	2	81	2007	14	4	93
1995	17	2	79	2008	13	1	79

1996	15	3	80	2009	29	2	86
1997	17	2	86	2010	13	2	81
1998	14	2	80	2011	8	0	76
1999	12	2	83	2012	18	3	83
2000	19	3	79	2013	11	1	83
2001	24	1	81	2014	18	4	100
2002	12	2	85	2015	13	5	101

The longest dry spell was observed during 2009, which lasted for 29 days. Total number of non-rainy days i.e., days with rainfall less than 2.5 mm were found to be highest during 2015 (101 days) followed by 2014 (100).

Hisar

Heat wave and cold wave events in the current two decades (1995-2014) were analyzed in comparison with their normal values (1970-2014). Latest definition of heat wave and cold wave given by IMD was used for the analysis. Heat wave frequency was analyzed for the months March to September and the results are presented in Table 3.5

Table 3.5 Frequency of days of heat wave estimated using IMD criteria at Hisar

Month	Period: 1975-2014		Period: 1995-2014	
	Days of heat wave	Days of heat wave /year	Days of heat wave	Days of heat wave /year
Mar	3	0.1	3	0.2
Apr	34	0.9	23	1.2
May	97	2.4	47	2.4
Jun	111	2.8	45	2.3
Jul	52	1.3	24	1.2
Aug	19	0.5	9	0.5
Sept	1	0.0	0	0.0
Annual	317	7.9	151	7.6

Eight days of heat wave per annum were observed as normal at Hisar. Maximum days of heat wave were observed in June (2.8 days) followed by May (2.4 days). During 1995-2014 on an average 7.6 days of heat wave /year observed, which is almost equal to the normal.

Cold wave frequency was analysed for winter period i.e. from October to March and the results are presented in Table 3.6

Table 3.6 Frequency of days of cold wave estimated using IMD criteria at Hisar

Month	Days of cold wave (1975-2014)	Normal Days of cold wave/year (1975-2014)	Days of cold wave (1995-2014)	Days of cold wave/ year (1995-2014)
Oct	3	0.1	0	0.0
Nov	1	0.0	1	0.1
Dec	21	0.5	15	0.8
Jan	51	1.3	46	2.3
Feb	37	0.9	20	1.0
Mar	7	0.2	2	0.1
Annual	120	3.0	84	4.2

At Hisar, normal days of cold wave per annum were worked out as three. Maximum days of cold wave were observed in January, followed by February. During 1995-2014, on an average, 4 days of cold wave /year were observed, which is higher than the normal.

Jabalpur

Water availability period at Jabalpur for crop production was calculated by estimation of moisture index (MI). Daily weather data during the period 1983-2013 was used for estimation of reference evapotranspiration using FAO Penman-Monteith equation and the results are presented in Table 3.7

Table 3.7 Average month-wise proportion of ET_o components, and water availability period at Jabalpur (Computed from of 1983-2013 weather data of Jabalpur)

Month	ET_o (mm/month)	ET_o components proportion*		Mean monthly rainfall (mm)	Aridity index	Moisture index
		Energy balance (%)	Aerodynamic component (%)			
January	66.83	81	19	19.97	0.30	-70
February	83.56	80	20	25.44	0.30	-70
March	124.59	75	25	15.43	0.12	-88
April	158.89	67	33	4.65	0.03	-97
May	197.16	60	40	11.21	0.06	-94
June	162.10	65	35	181.07	1.12	12
July	110.77	81	19	430.3	3.88	288

August	99.66	87	13	456.96	4.59	359
September	104.71	88	12	278.44	2.66	166
October	102.77	87	13	36.03	0.35	-65
November	74.80	82	18	12.85	0.17	-83
December	61.50	81	19	10.62	0.17	-83

The ET_0 was more during April to June and less in the months of November to February. The water availability period from the moisture index (%) of Jabalpur, Madhya Pradesh, it was understood that majority of the years come under moist sub-humid to dry sub-humid climate (Fig. 3.6).

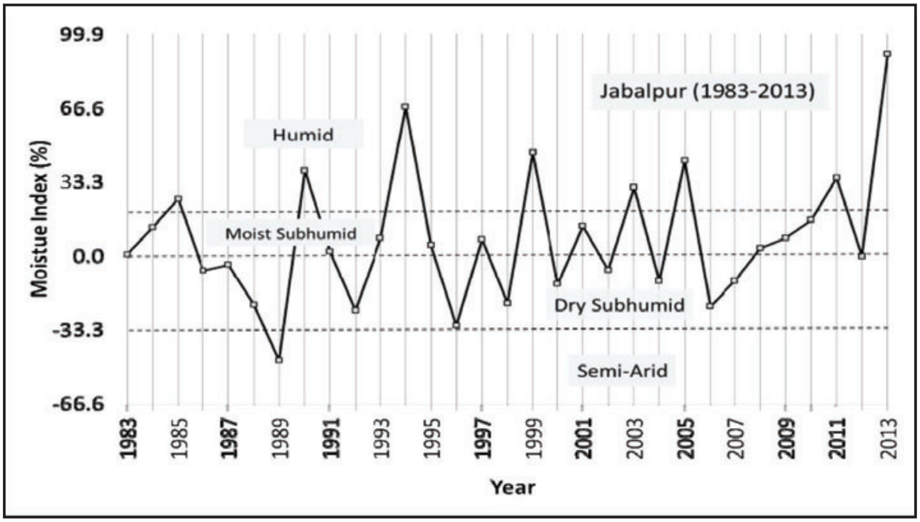


Fig. 3.6 Moisture index at Jabalpur from 1983-2013

The semi-arid climate occurred very rarely (only once) in this region. Humid climate occurred four times in last 15 years of the study period. Jabalpur is likely to continue in its normal climate or slightly tend towards wetter side and will have better moisture conditions in the future. Rainfed farmers of Jabalpur region can sustain their crop production under present climate variability and become resilient to future climate change, by adopting improved practices through Integrated Watershed Management with climate-smart crop varieties.

Jorhat

Trend analysis of weather parameters at Jorhat was undertaken for the period 1990-2015 using daily weather data. The significant results are presented in Table 3.8

Table 3.8 Trend analysis of weather parameters using Mann-Kendall test at Jorhat (1990-2015)

Sl. No.	Weather parameter	Unit	Mean value	Trend	Statistical significance	Rate of change per annum
1	Annual Maximum Temperature	°C	28.6	↑	**	0.036 °C
2	Annual Minimum Temperature	°C	19.1	↑	NS	0.015 °C
3	Annual Mean Temperature	°C	23.9	↑	**	0.025 °C
4	Annual Rainfall	mm	1822.1	↑	NS	2.88 mm
5	Daily RH (Morning)	%	92.2	↑	**	0.141%
6	Daily RH (Evening)	%	70.8	↓	NS	-0.105%
7	Mean RH	%	81.5	No trend	--	--
8	Daily BSSH	Hrs.	5.0	↓	**	0.026 hrs.

*↑-increasing, ↓-decreasing, NS-Non Significant, **-Significant at 99%*

Among all these eight weather parameters, annual maximum temperature, mean temperature and daily morning relative humidity showed highly significant increasing trend of 0.036 °C, 0.025 °C and 0.14% per year, respectively. Daily bright sun shine hours were found to be showing highly significant decreasing trend of 0.03 hours per year.

Ludhiana

Climate variability study was undertaken at Ludhiana center by studying trends in weather parameters during *kharif* and *rabi* seasons for different locations of Punjab and the results are presented in Table 3.9.

The annual maximum temperature increased in North-eastern Punjab (Ballowal Saunkhri), Central Punjab (Jalandhar and Patiala) and South-western Punjab (Bathinda). The annual, *kharif* and *rabi* season minimum temperatures have increased in Central Punjab (Ludhiana, Jalandhar and Patiala) and South-western Punjab (Bathinda). Evaporation showed a significant decreasing trend in North-eastern Punjab (Ballowal Saunkhri) and Central Punjab (Ludhiana). Annual and *kharif* season rainfall showed significant increasing trend at Jalandhar (Central Punjab), while *rabi* season rainfall showed significant decreasing trend at Bathinda (Southwestern Punjab).

Table 3.9 Mann Kendall trend statistics of meteorological parameters on annual, *kharif* and *rabi* season for different locations in Punjab

Meteorological Parameter	North Eastern Punjab	Central Punjab				South Western Punjab
	Ballowal Saunkhri (1984-2012)	Amritsar (1970-2012)	Jalandhar (1971-2010)	Ludhiana (1970-2012)	Patiala (1970-2012)	Bathinda (1977-2012)
Maximum Temperature						
Annual	+2.13**	-1.22 (NS)	-4.43***	+0.15(NS)	+2.22**	-2.68***
Rice (*Kharif*)	+2.03**	-1.66*	-4.97***	-1.59 (NS)	+0.61 (NS)	-2.45***
Wheat (*Rabi*)	+1.40 (NS)	-0.99 (NS)	-2.66***	+1.36 (NS)	+2.02**	-1.58 (NS)
Minimum Temperature						
Annual	+0.46 (NS)	+0.45 (NS)	+3.91***	+6.14***	+3.20***	+1.93*
Rice (*Kharif*)	+0.66 (NS)	+0.53 (NS)	+2.99***	+5.79***	+3.50*	+1.49 (NS)
Wheat (*Rabi*)	-0.26 (NS)	+1.43 (NS)	+3.72***	+5.57***	+1.90*	+1.53 (NS)
Maximum Relative Humidity						
Annual	+4.05***	-	-1.150 (NS)	+4.19***	-	+2.88***
Rice (*Kharif*)	+3.83***	-	-2.04**	+3.54***		+1.85***
Wheat (*Rabi*)	+2.00 **	-	+0.29 (NS)	+3.80***	-	+3.03***
Minimum Relative Humidity						
Annual	+4.16***	-	+3.64***	+5.07***	-	+0.96*
Rice (*Kharif*)	+3.12***		+2.83***	+4.33***		+1.16**
Wheat (*Rabi*)	-2.29**	-	+3.02***	+3.53**	-	0.00 (NS)
Sunshine hour						
Annual	-0.98 (NS)	-	-0.48 (NS)	-3.85***	-	-
Rice (*Kharif*)	-1.81*		+0.14 (NS)	-2.80***		
Wheat (*Rabi*)	+0.37 (NS)	-	-0.38 (NS)	-4.09***	-	-
Pan Evaporation						
Annual	-4.94***		-	-4.01***	-	-0.62***
Rice (*Kharif*)	-4.45***			-4.04***		-1.71***
Wheat (*Rabi*)	-2.77***		-	-2.49**	-	+1.40***
Rainfall						
Annual	-1.29 (NS)	-0.75(NS)	+3.36***	+0.68(NS)	-0.37(NS)	-1.29 (NS)
Rice (*Kharif*)	-1.25 (NS)	-0.63 (NS)	+3.25***	+0.90 (NS)	-0.29 (NS)	-0.83 (NS)
Wheat (*Rabi*)	-1.44 (NS)	-0.56(NS)	+1.28 (NS)	0.00 (NS)	-1.12(NS)	-2.30**

The change in number of rainy days during south west monsoon season over West Bengal was analyzed using 20 years daily rainfall data (1996-2015). Trend analysis indicated a declining trend in major parts of Cooch- Behar, North 24 Parganas, East Midnapur and Bankura districts (Fig. 3.7). Rainy days during SW monsoon showed an increasing trend in some stations of Burdwan, Nadia, Bankura and Hooghly districts. Increase in monsoon rainfall in the Red lateritic zones of Birbhum and some parts of Burdwan will enhance the soil moisture storage.

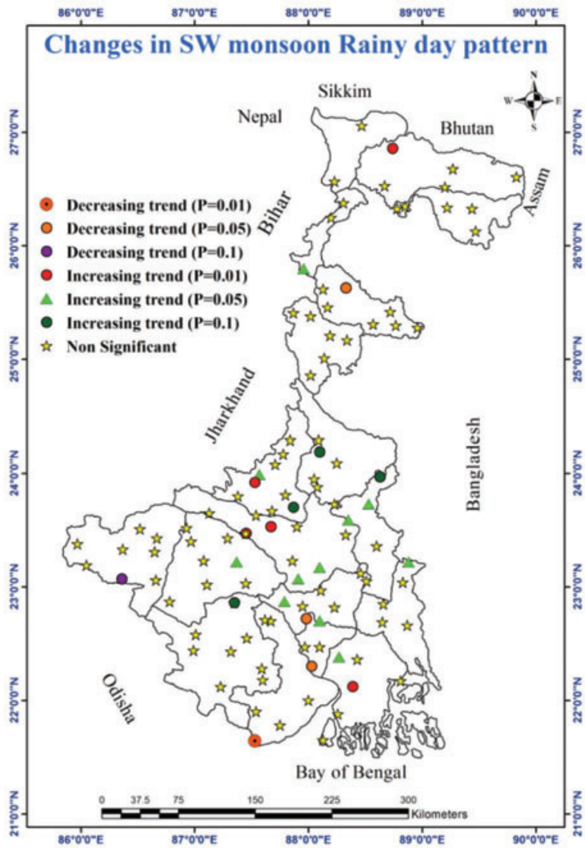
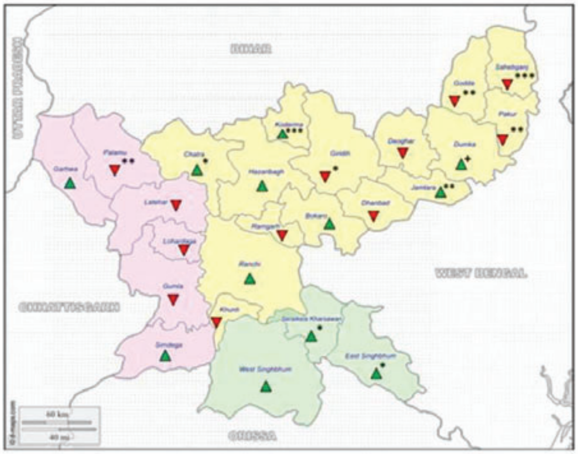


Fig. 3.7 Changes in rainy-days pattern in West Bengal

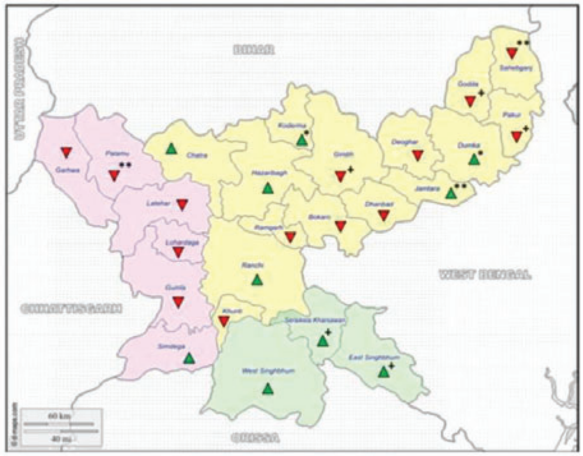
Ranchi

Trend analysis of annual as well as monsoon rainfall was tested by Mann-Kendall test in 24 districts of Jharkhand using long term daily weather data (1983-2015). Districts situated under zone IV showed a decreasing trend in monsoon and annual rainfall, except Simdega district [Fig. 3.8 (a), (b)]. Among the 15 districts of zone IV, nine districts showed a decreasing trend in rainfall which was significant for Giridih, Godda, and Sahebganj and Pakur districts. Significant increasing trend was observed in Koderma, Dumka and Jamtara districts. Saraikela, East and west Singhbhum districts, coming under zone VI showed an increasing trend during both annual and monsoon season.

Occurrence of dry spells (*i.e.* continuous period with less than 2.5 mm rainfall) of 10 days was increasing in Zone V. Under zone IV, wherever monsoon as well as annual rainfall showed a decreasing trend, occurrence of dry spell was more. A decreasing trend in occurrence of dry spells was observed in Chatra, Koderma, Hazaribagh, Deoghar, Dumka and Jamtara districts [Fig. 3.8 (C)]. Occurrence of wet spell (rainfall ≥ 25 mm for 3 days) was decreasing in Zone V, except Simdega, where it showed an increasing trend. Under zone IV, a mixed trend was found. Ranchi, Charta, Hazaribagh, Koderma, Bokaro, Deoghar, Jamtara and Dumka districts showed increasing trend, whereas Ramgarh, Giridih, Dhanbad, Godda, Sahebganj and Pakur districts, exhibited a decreasing trend [Fig. 3.8(d)].

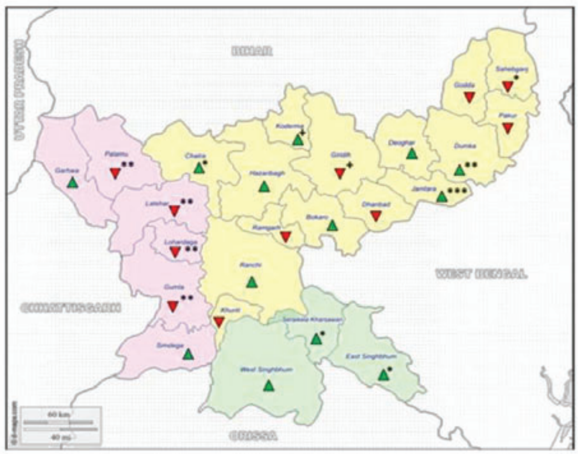


(a) Annual rain



(b) SWM rain

(c) Rain < 2.5 mm for 10 days



(d) Rain ≥ 25 mm for 10 days

Fig. 3.8 Trends of (a) annual (b) southwest monsoon rainfall, (c) dry spell with rainfall < 2.5 mm for 10 days (d) spell with rainfall ≥ 25 mm for 3 days using Mann-Kendall test in 24 districts of Jharkhand during 1983-2015

Thrissur

Spatial variation in rainy days during annual and southwest monsoon period in Kerala was analyzed using long-term daily weather data and the results are presented in Fig. 3.9. Annual rainy days are highest at Kottayam district (129) and lowest at Thiruvananthapuram (96). On an average, southwest monsoon rainfall in the state occurs in 75 rainy days. At the zonal level, highest number of rainy days is noticed in Northern zone (83) and lowest over South zone (56). At the district level, Kannur district recorded maximum (91) rainy days and Thiruvananthapuram, the minimum (49).

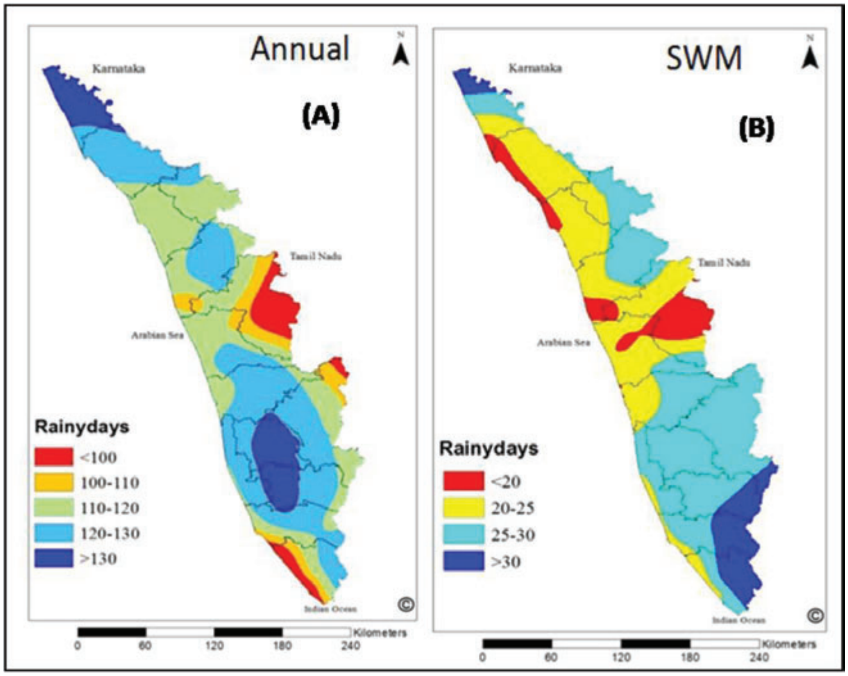


Fig. 3.9 Spatial variation of (A) annual and (B) southwest monsoon rainy days across Kerala

Udaiapur

Demarcation of productivity zones of wheat in Rajasthan was undertaken. Yield gap analysis was done to quantify the difference between the potential productivity of a crop in a region and its yield at farm level. The criteria adopted in the demarcation of the zones are based on area as well as yield. Districts were placed in different categories depending upon the area and productivity levels and seven categories were considered *viz.*, High area-High yield (HH), High area - Medium yield (HM), Medium area - High yield (MH), Medium area - Medium yield (MM), Medium area - Low yield (ML), Low area - Medium yield (LM) and Low area - Low yield (LL). The result of the analysis is presented in Fig. 3.10.

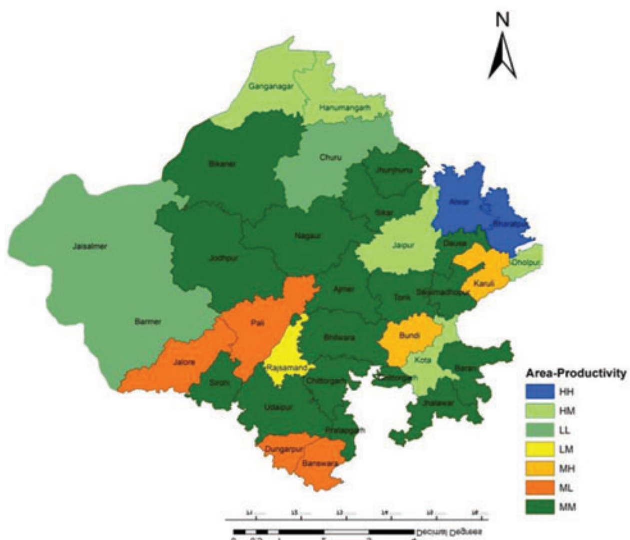


Fig. 3.10 Potential area and productivity of wheat in Rajasthan

On the basis of above criteria, Banswara, Pali, Jalore and Dungarpur districts comes under ML category and Rajsamand is under LM category, where there is a requirement to increase area under wheat and strategies to enhance productivity. Three districts viz., Churu, Jaisalmer and Barmer comes under LL category. Alternative options may be suitable in these districts during *rabi* season instead of wheat.

Samastipur

Length of rainy season in all the 38 districts of Bihar were worked out based on forward and backward accumulation criteria of weekly rainfall at two different probability levels, *viz.* 50 and 75 per cent.Using this criteria, the duration of rainfed cropping period in the districts under various agroclimatic zones of Bihar were identified. The progress (in terms of SMW) of 75 mm forward accumulated rainfall (onset of rainy season) for sowing of rainfed crops across various regions of the state have been presented in Fig. 3.11.

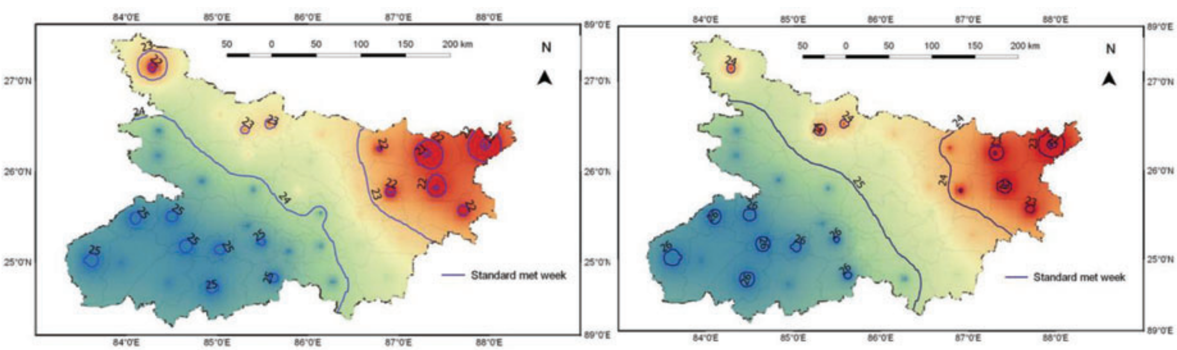


Fig. 3.11 Onset of rainy season based on forward accumulation of 75 mm rainfall at (A) 50 % and (B) 75% probability level for Bihar.

Early onset of monsoon takes place in the north eastern parts of the state, while late onset happens in the districts under Zone III-B. Based on 200 mm forward accumulated rainfall, the earliest transplanting of rice could be undertaken in the northeast part of the state. Such information could be useful in forming guidelines for the farmers to take up sowing of rainfed upland crops and transplanting of low land rice based on rainfall accumulation criteria.

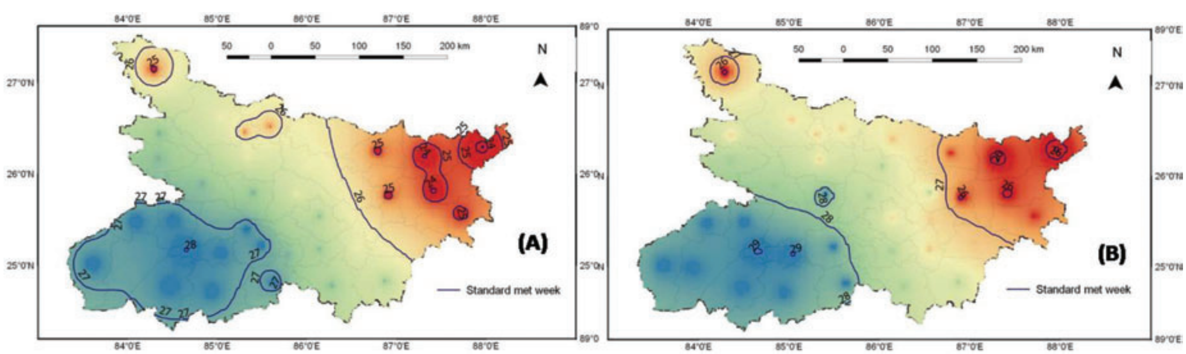


Fig. 3.12 Starting week of puddling operation for rice transplanting at (A) 50 % and (B) 75% probability level for Bihar.

4. Crop Weather Relationships

Weather plays an important role in agricultural production. It has direct influence on crop growth, development,yield and indirect influence on the incidence of pests and diseases.The water needs, radiation use efficiency, photosynthesis and fertilizer requirements are also influenced by weather. Weather aberrations may cause physical damage to crops and soil erosion. The quality of crop produce during movement from field to storage and transport to market depends on weather. Though weather or climate is the least manageable natural resource, understanding of its interaction with agricultural parameters was found to be a powerful tool to develop weather based management strategies in agriculture that will enhance benefits from positive interactions and minimize the losses from negative interactions.

Many physiological processes in the crop plants are governed by the micro environment in which they grow. All crop growth models (dynamic/mechanistic/deterministic) inadvertently use relations between crop growth and weather elements. A better understanding of these relationships enable scientists to estimate location specific or regional crop yields in advance. The information on crop weather relations also helps in development of genotypes/production systems and in designing management strategies during both growing season and post-harvest period. The results of the research carried out under crop-weather relationships program in different crops at different centers are discussed hereunder:

Kharif 2015

Rice

Faizabad

Influence of cultivars and growing environments on radiation interception and radiation use efficiency (RUE) was studied at Faizabad. Three cultivars (Sarjoo-52, NDR-359 and Swarna) were grown under three growing environments (5 July, 20 July and 4 Aug 2015). Cumulative Absorbed Photosynthetically Active Radiation (APAR) was measured in MJ/m^2 at periodic intervals using line quantum sensor and the results are presented in Table 4.1.

Table 4.1: Periodic cumulative APAR (MJ/m^2) of rice as affected by growing environments and cultivars at Faizabad

	DAT						
Treatments	**15**	**30**	**45**	**60**	**75**	**90**	**Harvest**
Growing Environment							
July 5	48.8	114.2	182.4	290.6	371.8	409.2	463.3
July 20	46.2	109.9	180.6	284.2	332.1	381.5	446.5
Aug 4	41.9	108.7	164.5	262.5	299.8	353.7	406.8
Cultivars							
Sarjoo-52	46.2	108.4	169.3	262.9	334.8	390.7	418.5
NDR 359	46.5	110.5	163.6	281.5	355.7	361.4	450.7
Swarna	48.7	112.6	179.5	286.1	361.9	392.7	456.8

DAT – Days after transplanting

Highest cumulative APAR was recorded under July 5th transplanting followed by July 20th at all the stages, and the lowest was under the crop transplanted on 4 August. It ranged from 407 - 463 MJ/m^2 at the harvesting stage across all the three growing environments or transplanting dates. Among the varieties, Swarna recorded higher value of cumulative APAR, compared to NDR-359 and Sarjoo-52 at all stages of crop. Radiation use efficiency was calculated from APAR and yield data and is presented in Table 4.2

Table 4.2: Radiation Use Efficiency (g/MJ) of rice as affected by cultivars and growing environments at Faizabad

	DAT						
Treatments	15	30	45	60	75	90	Harvest
Growing Environment							
5 July	1.8	2.1	2.8	2.6	2.7	2.6	2.5
20 July	1.6	1.9	2.6	2.2	2.4	2.3	2.2
04 Aug	1.2	1.2	2.1	2.1	2.2	2.6	2.0
Cultivars							
Sarjoo-52	1.5	1.2	2.0	2.3	2.3	2.2	2.2
NDR 359	1.3	1.4	2.4	2.7	2.5	2.6	2.5
Swarna	1.8	1.7	2.6	2.7	2.9	2.6	2.7

Among different growing environments studied, crop transplanted on 5th July recorded highest RUE at all stages of crop growth, followed by 20th July and 4th Aug transplanted crop. Among cultivars, Swarna recorded highest RUE at harvest (2.7g/MJ), compared to NDR-359 (2.5 g/MJ) and Sarjoo-52 (2.2 g/MJ).

Kanpur

Effect of growing environments and cultivars on dry matter production, heat use efficiency and grain yield was studied at Kanpur center. Cultivars NDR-359 (V_1), CSR-27 (V_2), Sarjoo-52 (V_3) and Swarna (V_4) were exposed to three growing environments [transplanted on 2nd July (D_1), 12th July (D_2) and 22nd August (D_3)] and periodic observations on dry matter accumulation, final grain yield were made (Table 4.3).

Table 4.3 Effect of growing environments and cultivars on yield, yield attributes and HUE of *kharif* rice at Kanpur

Treatment	Yield (t/ha)			Harvest index (%)	HUE (kg/ha/°Cday)
	Grain	Straw	Biomass		
Growing environment					
2 July	4.4	6.4	10.8	40.3	3.91
12 July	3.9	6.0	9.9	39.2	3.78

22 August	3.0	5.9	8.8	33.7	3.56
SE + (D)	0.42	0.50	0.88	0.11	
CD 5 %	1.04	1.25	2.20	0.27	
Cultivars					
V1	4.2	6.4	10.5	39.4	4.00
V2	3.4	6.0	9.4	36.2	3.78
V3	3.7	6.1	9.7	37.5	3.78
V4	3.7	6.0	9.7	37.9	3.43
SE + (D)	0.50	0.72	1.08	0.27	
CD 5%	1.04	1.48	2.22	0.56	

The highest grain (4.4 t ha^{-1}), straw (6.4 t ha^{-1}), biomass (10.8 t ha^{-1}) and harvest index (40.3%) were recorded for crop transplanted on 2nd July, followed by 22nd August transplanted crop. Among cultivars, NDR-359 recorded highest grain (4.2 t ha^{-1}), straw (6.4 t ha^{-1}), biomass (10.5 t ha^{-1}) and harvest index (37.9), followed by Swarna, Sarjoo-52, CSR-27 respectively. The timely (2nd July) planted crop experienced optimum temperature, rainfall and sunshine hours during growth and development period compared to delayed transplanted paddy. That could be the reason for low yield and yield attributing characters for late transplanted paddy.

Similar trend was observed for HUE also. Crop transplanted on 2nd July recorded maximum HUE (3.91 kg/ha/°Cday) and among cultivars, NDR-359 recorded highest HUE (4 kg/ha/°C day).

Relationship between weather parameters and grain yield of rice was also studied and the results (Fig. 4.1) indicated that both mean maximum temperature and mean daily average temperature during vegetative stage of the crop showed significant positive relation with grain yield (significant at P=0.05). However, mean maximum temperature (R^2=0.60) showed higher correlation with grain yield, compared to daily average temperature (R^2=0.53).

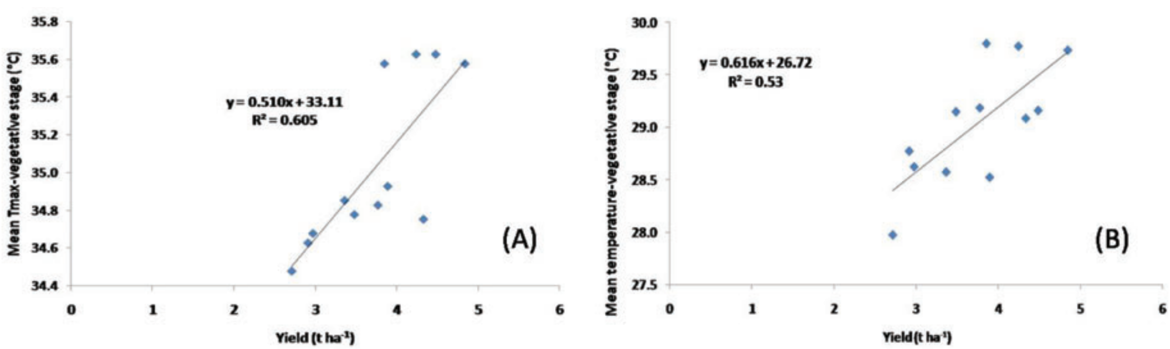


Fig. 4.1 Relationship of (A) mean maximum temperature and (B) mean temperature during vegetative stage of rice with grain yield during *kharif* 2015 at Kanpur

Mohanpur

Rice cultivars Swarna, Satabdi and Nayanmani were exposed to four growing environments (transplanted on 16th June, 1st July, 16th July and 31st July 2015) to study the crop weather relationships. Relationship between cumulative intercepted radiation and biomass of different cultivars under different dates of transplanting was studied and the results are presented in Fig. 4.2. The slope of the regression is known as radiation use efficiency (RUE). Cultivar *Nayanmani* transplanted on 31st July has the highest RUE (2.76 gm MJ^{-1}) followed by *Swarna,* which recorded RUE value of 2.67 gm MJ^{-1}. *Satabdi* transplanted on 16th June had the lowest RUE value (1.99 gm MJ^{-1}).

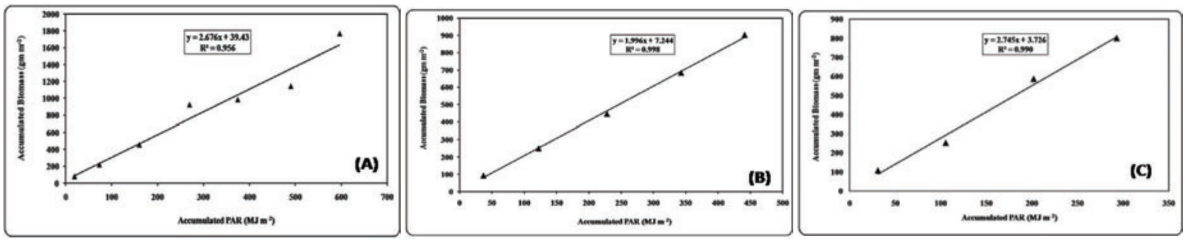


Fig. 4.2 Relationship between cumulative intercepted radiation and biomass of (A) Swarna (B) Satabdi and (C) Nayanmani transplanted on 16th June, 16th July and 31st July, respectively.

Raipur

Cultivars Swarna, MTU 1010 and Mahamaya were grown under three growing environments (sown on 1st, 15th and 30th June 2015) to study the crop weather relationship. The effect of cultivars and growing environments on heat and radiation use efficiencies was studied and the results are presented in Table 4.4 and 4.5.

Table 4.4 Heat use efficiency ($g/m^2/^oday$) of rice varieties as influenced by different growing environments

Varieties/Sowing Date	1 June	15 June	30 June	Mean
Swarna	0.29	0.33	0.34	0.32
Mahamaya	0.23	0.30	0.31	0.28
MTU1010	0.22	0.28	0.30	0.27
Mean	0.26	0.32	0.32	

Among the varieties, Swarna recorded highest HUE, averaged over all three growing environments. Highest HUE was found in crop sown on 30th June, followed by 15th June sown crop. However, the difference in HUE between the crop sown on 30th June and15th June is almost negligible. All the three varieties recorded highest HUE when subjected to third growing environment.

Table 4.5 Radiation use efficiency (g/m²/MJ) of rice varieties as influenced by different sowing dates

Varieties	1 June	15 June	30 June	Mean
Swarna	0.77	0.86	0.85	0.82
Mahamaya	0.63	0.78	0.81	0.74
MTU1010	0.60	0.76	0.79	0.72
Mean	0.69	0.83	0.82	

Similar trend was observed in RUE also. Highest RUE was recorded for Swarna, across all the growing environments. RUE of all the varieties was lowest in first growing environment (1st June) compared to theRUE in other two growing environments.

Samastipur

Results of field experiments on rice conducted at Samastipur center during *kharif* 2009-2014 were pooled and thermal time requirement and accumulated heat units were estimated. The results of the study are presented in Table 4.6.

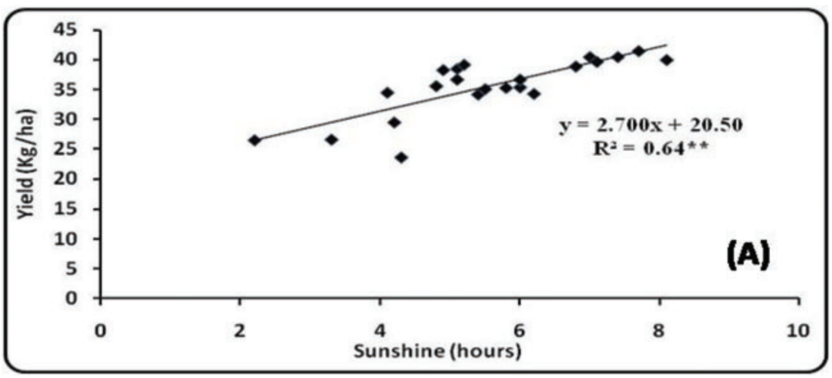
Table 4.6 Thermal time and heat unit requirements of *kharif* rice sown at different sowing windows at Pusa, Samastipur during 2009-2014

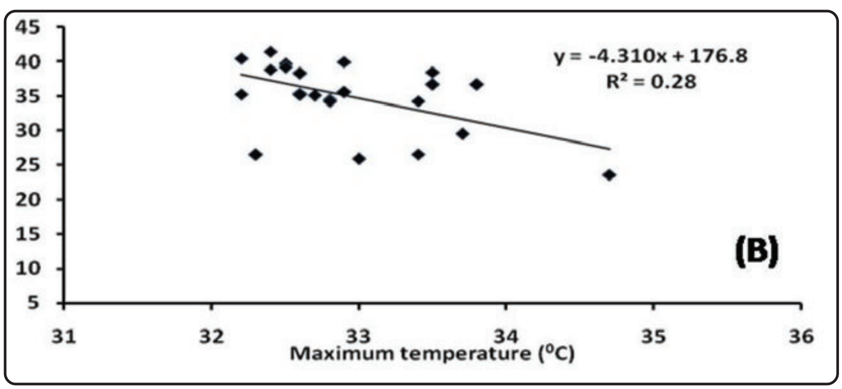
Days after sowing						
Treatment	**Tillering**	**Booting**	**50% earhead**	**Milk**	**Dough**	**Maturity**
31 May	47.5	89.2	109.1	116.5	133.0	142.4
15 June	48.2	88.5	103.9	109.7	121.4	131.9
30 June	48.8	85.7	98.9	104.8	119.7	126.9
15 July	49.5	85.7	96.0	106.9	124.1	118.9
Mean	48.5	87.3	102.0	109.5	124.6	130.0
Accumulated heat units (day °C)						
31 May	955.9	1793.3	2175.7	2316.8	2622.7	2622.7
15 June	949.2	1748.6	2043.1	2156.1	2366.5	2366.5
30 June	979.8	1751.3	1941.7	2050.1	2307.0	2307.0
15 July	987.9	1676.7	1864.2	1965.9	2299.1	2299.1
Mean	968.2	1742.5	2006.2	2122.2	2398.8	2398.8

The results indicated that there is a lot of variation in number of days required for attaining a particular phenophase when the crop is exposed to different micro-environmental conditions or sown on different dates. The first three dates could be considered as normal sowing in this region, whereas 15th July represents late sowing of the crop. The data revealed that except tillering stage, in all other stages, a decrease in number of days with delay in sowing was observed. The crop required extra two days to reach the maximum tillering stage when sown on 15th July, compared to the sowing done on 31st May. The number of days required to attain 50 % flowering for 31st May sown crop was 109 days while they were only 96 days when sown on 15th July. The duration of crop from sowing to maturity was longer (142.4 days) in case of 31st May sowing compared to 15th July sowing (118.9 days),thus indicating the curtailment of crop duration by 1 day with delay in sowing by 2 days.

Similar observations were made in the case of accumulated heat units also. The amount of accumulated heat units increased with delay in sowing at tillering stage. However, in all other stages, accumulated thermal units decreased with delay in sowing dates. The 31st May sown crop availed more than 300 units of growing degree days or heat units from sowing to 50% flowering stage as compared to 15th July sown crop. The accumulated heat units calculated for 50 % flowering stage were 2175.7 and 1864.2 day °C, respectively under early and late growing conditions. At maturity, the requirements of accumulated heat units were 2622.7, 2366.5, 2307.0 and 2299.1 day °C for 31st May, 15th June, 30th June and 15th July-sown crops, respectively.

The relationships of mean bright sunshine hour (BSH) during flowering stage and maximum temperature (Tmax) during heading and flowering stages with grain yield of *kharif* rice were studied and the results are presented in Fig. 4.3.





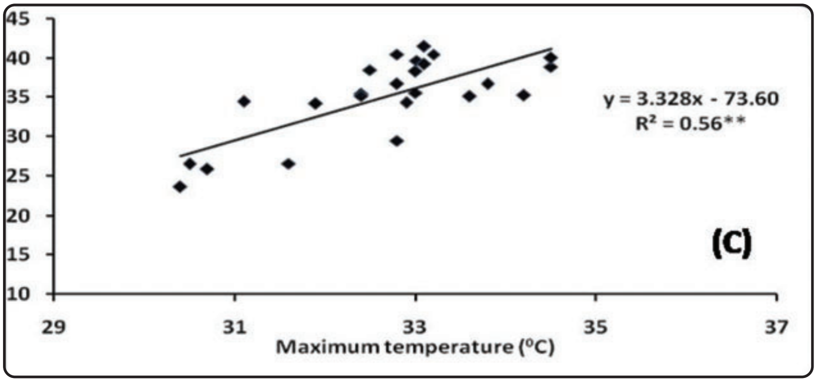


Fig. 4.3 Effect of (A) sunshine hours during flowering, (B) maximum temperature during heading and (C) maximum temperature during flowering stages on *kharif* rice in 2015 at Samastipur

The results indicated that mean bright sunshine hours (BSS) during flowering stage showed positive linear relationship with grain yield [Fig.4.3 (A)]. The coefficient of determination (R^2) of regression equation explained 64 per cent of total variability in grain yield. Highest grain yield was obtained at a mean BSS of 7 to 8 hours during flowering stage. Mean maximum temperature during heading stage registered negative linear relationship with grain yield [Fig. 4.3 (B)]. The coefficient of determination (R^2) of regression equation, though significant explained only 28 per cent of total variability in grain yield. It was observed that grain yield was higher at mean maximum temperature between 32.2 and 32.6 °C during heading stage. The relationship between grain yield and mean maximum temperature during flowering stage indicated that mean maximum temperature during flowering stage exhibited positive linear relationship with grain yield [Fig. 4.3 (B)]. The coefficient of determination (R^2) of regression equation explained 56 per cent of total variation in grain yield. The grain yield increased with increase in Tmax, with the highest grain yield being registered at mean Tmax of 33.4°C during flowering stage.

Thrissur

The field experiments were conducted in split plot design with five dates of planting at an interval of 15 days from June 5th to August 5th as the main plot treatments and two varieties

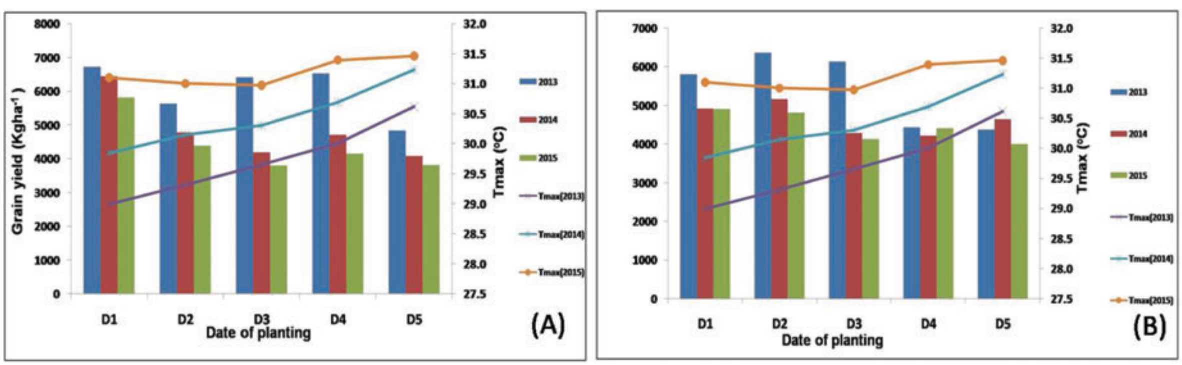


Fig.4.4 Influence of maximum temperature on grain yield of (A) Jyothi and (B) Kanchana rice cultivars during *kharif* 2013, 2014 and 2015 at Thrissur.

(Jyothi and Kanchana) as sub plot treatments with four replications. Influence of maximum temperature on grain yield was studied for *kharif* 2013, 2014, 2015 and the results are presented in Fig.4.4.

The highest grain yield in Jyothi was observed for the crop planted on June 5th (early planting)in both the years (6712 kg ha^{-1}and 6440 kg ha^{-1} respectively). The August 5th (late planting) planted crop recorded the lowest yield in Jyothi for both the years (4835 kg ha^{-1} and 4070 kg ha^{-1} respectively). In case of Kanchana, highest grain yield was observed with June 20th planted crop for both 2013 (6355 kg ha^{-1}) and 2014 (5160 kg ha^{-1}). The higher grain yield in June 5th crop of Jyothi and June 20th crop of Kanchana during both the years were attributed to increased number of filled grains per panicle and thousand grain weight. The grain yield was found to be reducing with delay in planting dates for both the varieties during both years, which may be due to increase in maximum temperature and decrease in rainfall which may reduce the number of filled grains per panicle and thousand grain weight. The grain yield was less during 2014 compared to 2013 for both the varieties [Fig. 4.4(A) and (B)], because of high temperature during 2014 at different phenophases of the crop stages. The yield reduction with delay in planting was also attributed to decrease in rainfall during both the years.

Influence of rainfall on grain yield of Jyoti and Kanchana rice varieties were also studied for the same period and the results are presented in Fig. 4.5.

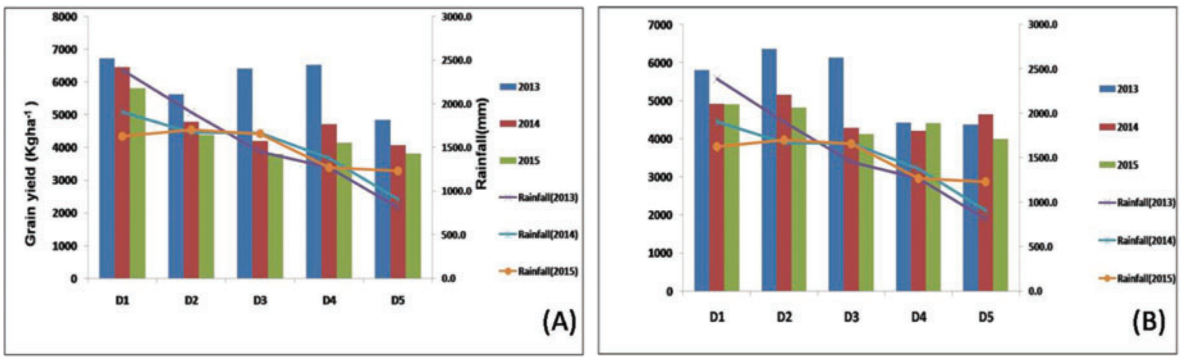


Fig.4.4 Influence of seasonal rainfall on grain yield of (A) Jyothi and (B) Kanchana rice cultivars during *kharif* 2013, 2014 and 2015 at Thrissur.

The results indicated that reduction in yield under late sowing (D5), compared to other sowing dates was due to lower rainfall received during the growing season of late sown crop. The decline in yield due to low rainfall under this date of sowing was observed in Jyothi variety only.

Maize

Jammu

Effect of growing environments on yield and heat use efficiency of maize cultivars Kanchan-517, Pratap Makka-3 and Kanchan-612 was studied by growing them under three growing environments (sown on 21st June, 2nd and 15th July).The yield and yield attributes of cultivars under different growing environments are presented in Table 4. 7.

Table 4.7 Effect of growing environments and cultivars on yield and yield attributes of maize at Jammu during *kharif* 2015

Treatments	Seed Yield (t/ha)	StrawYield (t/ha)	Coblength (cm)	Cobweight (gm)	No. of grains /cob	Test weight (gm)
Growing environments						
21 June 15	3.8	5.8	18.7	82.0	301.9	67.5
2 July 15	3.5	4.9	17.4	67.3	229.6	55.1
15 July 15	3.23	4.0	12.6	50.8	206.8	40.2
CD at 5%	0.13	0.41	0.99	8.19	27.5	6.67
Cultivars						
Kanchan-517	3.6	5.2	18.4	81.2	299.0	65.4
Pratap Makka-3	3.3	4.4	14.1	57.4	205.2	46.8
Kanchan-612	3.5	5.0	16.3	61.5	234.1	50.5
CD at 5%	0.13	0.41	0.99	8.19	27.5	6.67

Highest yield was observed for first date of sowing (3.8 t ha^{-1}) and it decreased with delay in sowing. The yield attributing characters viz.; number of grains per cob, cob length and cob weight also showed similar pattern as the seed yield. Higher test weight (67.5 g) was attained by the early sown (21st June) and lower test weight (40.2 g) by the late sown maize crop (15th July). The late sown crop varieties were affected by low mean temperature (15°C) at grain filling stage, which led to infertility, reduced grain size and produced lighter grains.

Heat use efficiency (g m^{-2} $^{o}C^{-1}$ day^{-1}) was worked out using accumulated dry matter data and accumulated growing degree days at different days after sowing (Table 4.8).

Table 4.8 Heat use efficiency (g/m^2/degree day) of maize at periodic intervals as influenced by different treatments.

Days after sowing	Date of sowing			Varieties		
	21 June 15	2 July 15	15 July 15	Kanchan-517	Pratap Makka-3	Kanchan-612
10	0.09	0.07	0.07	0.09	0.06	0.08
20	0.14	0.13	0.10	0.13	0.11	0.12
30	0.18	0.16	0.13	0.17	0.14	0.16
40	0.29	0.27	0.25	0.29	0.25	0.27
50	0.39	0.34	0.32	0.37	0.32	0.36
60	0.41	0.41	0.36	0.43	0.36	0.39

70	0.47	0.45	0.40	0.46	0.42	0.44
80	0.42	0.41	0.38	0.42	0.39	0.40
90	0.39	0.38	0.35	0.39	0.35	0.37
Mean	0.31	0.29	0.26	0.31	0.27	0.29

The results presented in Table 4.8 showed that higher HUE was recorded under early sown (21st June) crop at all the stages due to higher dry matter production. The progressive decrease in HUE was observed with delay in sowing in all the varieties. The maximum heat use efficiency in maize crop was observed at 70th day after sowing. Among the varieties, Kanchan-517 recorded highest HUE followed by Pratap Makka-3 and Kanchan-612, respectively at 70th day after sowing. The mean heat use efficiency of maize crop varieties under sub-tropical region of Jammu was found to be 0.31, 0.29 and 0.26 g m^{-2} $^{o}C^{-1}$ day^{-1} in 21st June, 02nd July and 15th July sowings, respectively.

Ludhiana

The data on the periodic growth attributes and radiation interception was recorded and extinction coefficient was estimated in the maize cultivar PMH-1 at 45, 60, 75 DAS and physiological maturity stages under different sowing dates during the crop years 2014 and 2015. The results are presented in Table 4.9 and 4.10.

The analysis indicated that plant height decreased with the delay in sowing from May to July during both the years. At 45 DAS, the leaf area index was higher under the first date of sowing as compared to the other sowing dates, whereas the fourth date of sowing recorded lower value of leaf area index. The data recorded at 15 days interval starting from the 45 DAS revealed that the incoming PAR was higher at the top of the canopy and reduced downward. Better capturing of solar radiation during vegetative stage was due to increased LAI under different sowing dates. The middle part of the maize canopy incepted higher PAR as compared to the bottom. The intercepted PAR in the maize canopy reduced with the delay in sowing during both the years which may be due to the reduced leaf area index of the crop with delayed sowing. The extinction coefficient increased with the delay in sowing during both the years. The crop sown during 4th week of May had lower value of extinction coefficient as compared to other sowing dates whereas crop sown during 2nd week of July had high value of extinction coefficient.

Pearl millet

Solapur

Cultivars Shanti (V_1), Mahyco hybrid (V_2) and ICTP – 8203 (V_3) were exposed to three growing environments [sown on second fortnight of June (S_1), July (S_2) and August (S_3)] to study the crop weather relationships. The pooled data during kharif 2011-2015 was anlyzed and effect of cultivars and growing environments or sowing dates on grain yield, consumptive use of moisture (CUM) and moisture use efficiency (MUE) was studied and the results are presented in Table 4.11.

Table 4.9 Albedo (%), PAR interception (%) and extinction coefficient (k) of maize cultivars sown in 4th week of May and 2nd week of June during *kharif* 2014 and 2015

Days after sowing	Plant height (cm)	Incoming PAR (Wm-2)			PAR Albedo (%)			PAR Interception (%)		LAI	Extinction coefficient (k)	
		Top	Middle	Bottom	Top	Middle	Bottom	Middle	Bottom		Middle	Bottom
4th Week of May 2014												
45	177.5	1475.4	220.0	97.5	4.4	7.5	8.5	80.7	11.6	4.3	0.44	0.63
60	280.7	1460.5	193.1	86.8	4.1	6.0	8.5	82.7	10.6	5.2	0.39	0.54
75	290.9	1265.9	268.8	188.5	4.9	8.2	9.6	73.8	9.5	4.4	0.35	0.43
Phy. Mat.	290.9	1096.0	470.3	386.5	6.6	8.7	9.7	50.5	10.5	2.4	0.35	0.43
4th Week of May 2015												
45	179.6	1333.0	182.6	73.6	3.7	6.9	8.5	82.6	11.0	4.4	0.45	0.66
60	283.9	1260.5	155.7	84.2	3.6	5.5	6.6	84.0	8.6	5.5	0.38	0.49
75	294.7	1211.9	204.9	121.9	4.3	5.2	6.8	78.8	10.3	4.7	0.38	0.49
Phy. Mat.	294.7	1133.4	442.5	341.3	4.7	7.9	8.7	56.3	10.5	2.6	0.36	0.46
2nd Week of June 2014												
45	173.2	1439.3	242.3	123.5	4.9	6.8	7.8	78.2	12.0	3.9	0.46	0.63
60	267.1	1277.8	194.6	113.1	5.0	6.1	7.2	79.8	10.5	4.4	0.43	0.55
75	280.5	1135.2	288.6	187.6	5.5	7.8	7.7	69.0	12.5	4.1	0.33	0.44
Phy. Mat.	280.5	1118.2	537.2	429.6	6.4	7.9	8.3	45.6	12.2	2.2	0.33	0.43
2nd Week of June 2015												
45	178.2	1410.4	211.2	105.7	2.5	6.9	6.6	82.2	9.2	4.1	0.46	0.63
60	272.8	1171.4	166.3	100.6	3.0	5.8	6.9	82.4	8.0	4.7	0.42	0.52
75	284.3	1125.8	277.2	174.4	3.8	6.7	6.8	71.3	11.3	4.4	0.32	0.42
Phy. Mat.	284.3	1085.8	518.4	408.1	4.6	5.9	7.0	47.1	12.0	2.4	0.31	0.41

Table 4.10 Albedo (%), PAR interception (%) and extinction coefficient of maize cultivars sown in 4th week of Juneand 2nd week of July during *kharif* 2014 and 2015

Days after sowing	Plant height (cm)	Incoming PAR (Wm-2)			PAR Albedo (%)			PAR Interception (%)		LAI	Extinction coefficient (k)	
		Top	Middle	Bottom	Top	Middle	Bottom	Middle	Bottom		Middle	Bottom
4th Week of May 2014												
45	165.8	1222.2	277.5	146.5	5.3	5.6	6.6	72.0	14.8	3.6	0.41	0.59
60	259.3	1209.9	241.6	119.7	5.0	5.3	7.1	75.0	14.1	4	0.40	0.58
75	277.0	1118.1	339.8	195.3	6.1	7.5	7.9	63.5	16.8	3.4	0.35	0.51
Phy. Mat.	277.0	1091.1	622.5	493.8	6.2	7.7	8.1	36.7	13.6	1.6	0.35	0.50
4th Week of May 2015												
45	173.2	1212.1	217.4	142.2	3.9	7.6	8.2	78.1	8.8	3.9	0.44	0.55
60	261.4	1185.5	185.9	111.6	4.0	7.1	8.1	80.3	9.1	4.3	0.43	0.55
75	280.8	1118.2	315.0	190.6	5.4	6.9	8.3	66.4	14.6	3.6	0.35	0.49
Phy. Mat.	280.8	1115.8	609.6	459.5	5.6	6.9	8.5	39.1	15.5	1.8	0.34	0.49
2nd Week of June 2014												
45	143.0	1210.9	441.6	296.2	6.3	6.7	7.1	57.2	15.9	2.6	0.39	0.54
60	250.6	1112.6	342.8	243.4	5.3	6.1	7.0	63.9	12.3	3.4	0.35	0.45
75	253.2	1104.5	496.5	367.0	5.4	6.3	7.1	49.7	14.3	2.7	0.30	0.41
Physiological maturity	253.2	1034.8	705.1	555.3	6.5	6.8	7.5	25.3	16.4	1.5	0.26	0.41
2nd Week of June 2015												
445	146.5	1188.1	377.1	276.0	4.4	7.6	8.1	63.3	10.8	2.7	0.43	0.54
60	252.6	1128.6	276.6	257.0	4.4	6.6	6.3	70.5	4.8	3.6	0.39	0.41
75	261.9	1110.4	419.1	320.0	4.7	6.7	7.0	56.9	11.3	3.0	0.32	0.41
Phy. Mat.	261.9	1064.9	678.8	557.7	5.8	7.2	8.1	29.9	12.6	1.6	0.28	0.40

Table 4.11 Effect of cultivars and sowing time on grain yield, consumptive use of moisture and moisture use efficiency in *kharif* pearl millet at Solapur(2011-15).

Treatment	GY(kg ha^{-1})	CUM (mm)	MUE (kg ha^{-1} mm^{-1})
S_1V_1	631.7	240.0	2.6
S_1V_2	651.7	231.0	2.8
S_1V_3	595.8	216.0	2.8
S_2V_1	1266.1	266.0	4.8
S_2V_2	1287.2	256.0	5.0
S_2V_3	1057.5	252.0	4.2
S_3V_1	1236.0	248.0	5.0
S_3V_2	892.7	247.0	3.6
S_3V_3	748.5	232.0	3.2

The moisture use efficiency (MUE) during total growth period of *kharif* pearl millet [Fig. 4.6 (A)] showed a linear relationship with grain yield. The MUE of 4 to 5 kg ha^{-1} mm^{-1} was found to be optimum for getting higher grain yield. RUE also showed similar linear relationship with grain yield [Fig. 4.6 (B)]. The analysis indicated that with an increase of RUE from 1.4 to 1.6 g MJ^{-1}, yield increased from 0.4 to 1.2 t ha^{-1}. The results further indicated that every increase of 0.1 g MJ^{-1} in radiation use efficiency, causes an increase of 25 kg ha^{-1} in grain yield of pearl millet.

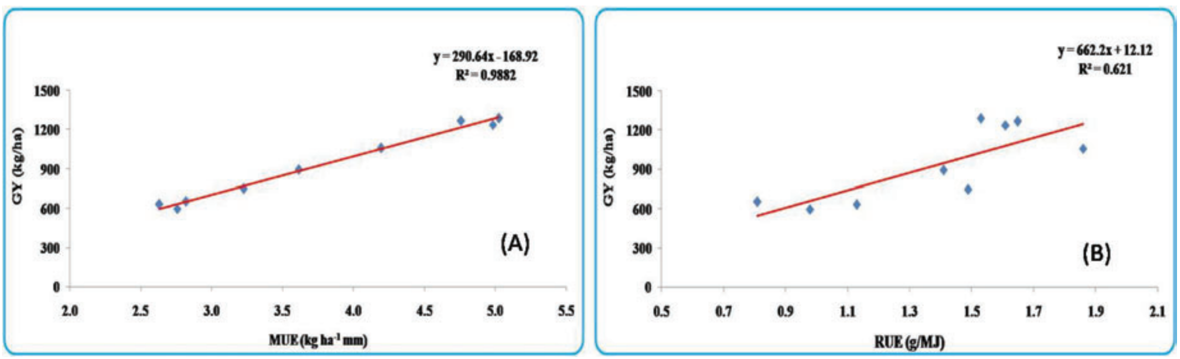


Fig. 4.6 Relationship of pearl millet grain yield with (A) moisture use efficiency and (B) radiationuse efficiency (pooled data during *kharif* 2011-2015) at Solapur

Pigeonpea

Vijayapura

Analysis of weather parameters relating to pod weight was taken up using the pooled experimental data of 2011-12 to 2015-16. Three cultivars, viz., TS-3R, Maruti (ICP-8863) and

BSMR-736 were grown under three growing environments (second fortnight of June and second fortnight of September) and three spacings (60x30 cm, 90x20 cm and 180x10 cm). The pod weight of pigeon pea showed highly significant positive correlation with diurnal temperature range at 150 DAS (Table 4.12). Contrastingly, the maximum temperature had significant negative relationship with pod weight. This suggests that the maximum temperature should be lower, and alongside this, there should be greater drop in minimum temperature.

Table 4.12 Correlation between periodical weather parameters and corresponding pod weight

Varieties	DAS	MAXT	MINT	RH_1	RH_2	TR	RHR	BSS	RF	GDD	SM
TS-3R	90	0.01	0.26	0.31	0.29	0.30	0.18	-0.29	-0.01	-0.25	-0.25
	120	-0.04	0.17	0.30	0.21	0.32	0.27	-0.21	0.06	-0.17	-0.17
	150	-0.28	0.18	0.60	0.59	0.52	0.54	-0.49	0.22	-0.63	-0.63
Maruti	90	0.01	0.25	0.31	0.29	0.30	0.18	-0.29	0.00	-0.23	-0.23
	120	-0.14	0.08	0.20	0.12	0.27	0.21	-0.15	0.07	-0.10	-0.10
	150	-0.50	0.12	0.74	0.69	0.79	0.76	-0.61	0.43	-0.50	-0.50
	180	-0.48	-0.38	0.02	0.08	0.57	0.34	-0.01	0.52	-0.06	0.00
BSMR-736	90	-0.01	0.11	0.11	0.08	0.09	0.06	-0.13	0.00	-0.30	-0.30
	120	-0.27	-0.13	-0.02	-0.08	0.07	0.03	0.02	0.07	0.07	0.07
	150	-0.86	-0.40	0.38	0.43	0.81	0.72	-0.30	0.53	-0.34	-0.34
	180	-0.69	-0.62	-0.17	0.01	0.68	0.41	0.12	0.61	0.02	-0.19
Pooled	90	0.01	0.26	0.32	0.29	0.30	0.18	-0.30	-0.01	-0.29	-0.29
	120	-0.16	0.03	0.15	0.07	0.21	0.16	-0.11	0.07	-0.06	-0.06
	150	-0.65	-0.05	0.67	0.67	0.83	0.79	-0.55	0.46	-0.58	-0.58
	180	-0.62	-0.50	0.00	0.11	0.69	0.44	0.00	0.58	-0.10	-0.12

(DAS- Days after sowing; TR-Temperature range; RHR – Relative humidity range; SM- soil moisture)

Soybean

Akola

Effect of photoperiod on crop phenology and its relationship with final yield was studied in soybean. The field experiment was undertaken with factorial randomized block design with four growing environments (28, 29, 30 and 31 standard meteorological weeks) and three cultivars (JS-335, JS-9305 and TAMS-98-21). Day length hours (sunrise to sunset hours) across different phenophases of soybean under different dates of sowing are presented in Fig. 4.7.

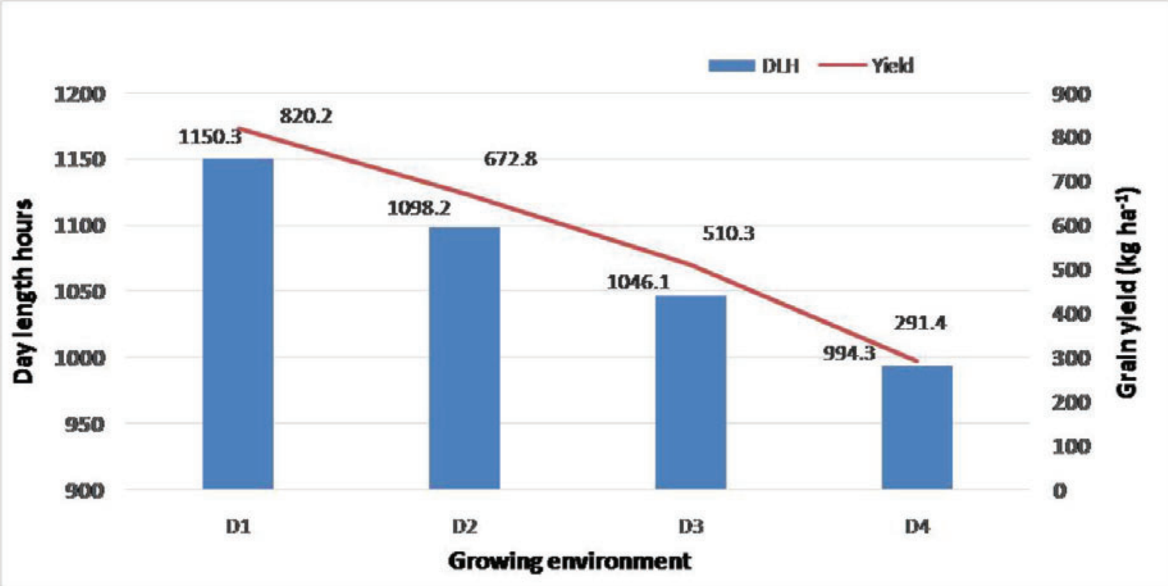


Fig. 4.7 Effect of day length hours (photo period) under different growing environments on yield of soybean at Akola

The crop accumulated maximum day length hours for all the phenophases when sown during 28 SMW. Photoperiod accumulation decreased with later sowings. Similarly, photoperiod hours decreased gradually across each subsequent phenophase of soybean crop. Longer photoperiod hours in earlier sowings caused extended duration of vegetative period as well as reproductive stages as compared to later sowings. The phenology of late sown soybean cultivars was shortened which reduced the total crop duration and finally resulted in lesser yield. Of all the growing environments, crop sown during 28 SMW recorded highest yield (820 kg ha^{-1}), and the crop sown during 31 SMW produced the lowest (291 kg ha^{-1}) yield. Among the varieties, JS-9305 recorded significantly higher seed yield (615 kg ha^{-1}) compared to other varieties.

Weather based soybean seed yield prediction models

Based on the field experimental data on soybean during 2007-15, weather based regression equations were developed to predict the seed yield of soybean at Akola. Seed yield (dependent variable) of soybean were regressed with a combination of weather parameters (independent variables) *viz.*, temperatures (maximum and minimum), diurnal temperature range and rainfall that were identified as relevant weather variables by the correlation analysis. Regression equations that were developed (Table 4.13) contain three sets of models, separately for each of the two cultivars and for both the cultivars combined.

Table 4.13 Seed yield prediction models for soybean based on temperature and rainfall (2007-15)

Cultivar	Phenological Stage	Model No.	Regression model	R^2
JS-335	PF	JS-I	Y = -14276.217 – 112.332 Tmax + 814.614 Tmin + 3.340 Rain	0.526
		JS-II	Y = 2241.347 – 159.994 DTR + 4.352 Rain	0.305
	SF	JS-III	Y = 2926.800 – 194.277 Tmax + 209.828 Tmin + 0.951 Rain	0.588
		JS-IV	Y = 2972.065 – 171.951 DTR + 2.144 Rain	0.586
	PF-SF	JS-V	Y = -268.502 – 171.177 Tmax + 297.830 Tmin + 2.595 Rain	0.629
		JS-VI	Y = 2818.403 – 199.001 DTR + 2.922 Rain	0.621
	Total growing period	S-VII	Y = -4090.043 – 181.485 Tmax + 468.281 Tmin + 1.605 Rain	0.574
		JS-VIII	Y = 3414.423 – 298.931 DTR + 1.755 Rain	0.556
TAMS 9821	PF	TAMS-I	Y = -10790.225 – 68.518 Tmax + 600.786 Tmin + 3.218 Rain	0.444
		TAMS-II	Y = 1953.450 – 126.884 DTR + 2.713 Rain	0.275
	SF	TAMS-III	Y = 427.023 – 98.717 Tmax + 173.863 Tmin + 1.433 Rain	0.570
		TAMS-IV	Y = 2385.172 – 126.131 DTR + 1.449 Rain	0.565
	PF-SF	TAMS-V	Y = 154.686 – 140.208 Tmax + 233.548 Tmin + 2.504 Rain	0.616
		TAMS-VI	Y = 2589.733 – 174.262 DTR + 2.474 Rain	0.613
	Total growing period	TAMS-VII	Y = 1932.532 – 228.015 Tmax + 281.275 Tmin + 0.792 Rain	0.535
		TAMS-VIII	Y = 3331.857 – 245.119 DTR + 0.728 Rain	0.523
Both cultivars	PF	BC-I	Y = -12721.872-117.098 Tmax + 752.189 Tmin + 3.726 Rain	0.491
		BC-II	Y = 2300.442 –170.330 DTR + 4.150 Rain	0.323
	SF	BC-III	Y = 374.262 – 118.189 Tmax + 206.756 Tmin + 1.748 Rain	0.589
		BC-IV	Y = 1754.487 –82.495 DTR + 3.788 Rain	0.535
	PF-SF	BC-V	Y = - 1819.122 – 227.233 Tmax + 455.017 Tmin + 0.706 Rain	0.636
		BC-VI	Y = 3761.252 – 279.060 DTR + 1.175 RF	0.618

	Total growing period	BC-VII	Y = 838.423 – 242.335 Tmax + 344.124 Tmin + 1.191 Rain	0.572
		BC-VIII	Y = 3438.234 – 277.862 DTR + 1.267 Rain	0.569

The equations developed indicated that coefficient of determination (R^2) was higher in equations considering the combined influence of maximum and minimum temperatures and rainfall rather than the combination of diurnal temperature range and rainfall, especially during pod formation-seed development period in both the cultivars. The coefficient of determination of seed yield by combining the influence of maximum temperature, minimum temperature and rainfall varied from 53% to 63 % in JS-335 and 44 to 61% in TAMS 9821 while the R^2 was 49 to 64% with both the cultivars considered together.

Water use indices for soybean

Different water use indices over the total growing period of soybean under different growing environments (sowing dates) and cultivars are presented in Table 4.14.

Table 4.14 Water use indices for soybean as influenced by growing environments and cultivars at Akola (2015)

Treatment	Seed yield (kg ha^{-1})	Eta (mm)	Etp (mm)	WRSI (%)	WP (kgha^{-1}mm^{-1})
Sowing time (SMW)					
28	820	321.5	381.0	0.84	2.55
29	673	305.0	361.0	0.85	2.21
30	510	279.4	344.2	0.81	1.83
31	291	252.6	319.7	0.79	1.15
Cultivar					
JS-335	580	291.6	350.2	0.83	1.99
JS-9305	615	284.2	344.2	0.82	2.16
TAMS-98-21	526	293.0	360.0	0.81	1.80

Actual (Eta) and potential (Etp) crop water use were higher under early sowing and decreased with later sowings. Water requirement satisfaction index (WRSI), an indicator of crop performance based on the availability of water to the crop during a growing season, was more in earlier sowings indicating lesser degree of yield reduction related to water deficit. Water productivity (WP), the ratio of yield to actual crop water use, was maximum under early sowing (28 SMW) and decreased with later sowings. Among the varieties, TAMS-98-21 showed higher Et_a and Et_p, followed by JS-335 and JS-9305. WP was higher with TAMS-98-21 followed by JS-335 and JS-9305.

Jabalpur

Three soybean cultivars (JS-95-60, JS-20-29 and JS-97-52) were grown under three growing environments (sown on 19th June, 7th July and 4th Aug 2015) to study the crop weather relationships. Relationship of growing degree day (°C day) and grain yield was attempted and is presented in Fig.4.8.

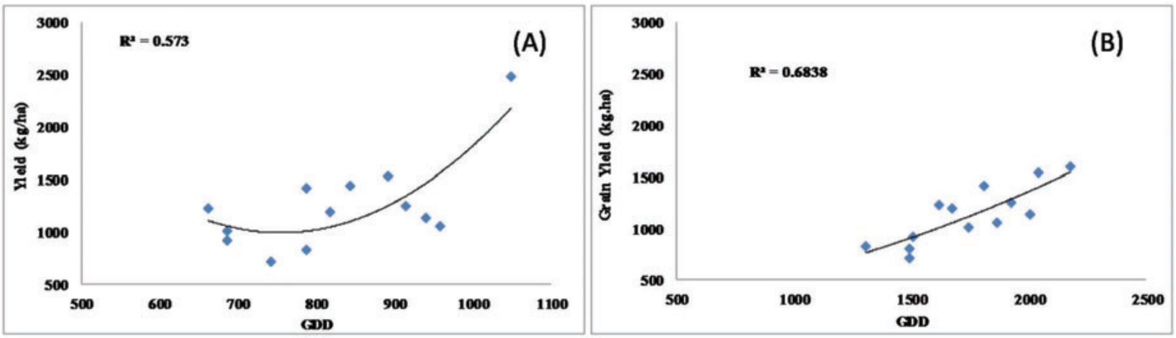


Fig. 4.8 Relation between grain yield (kg/ha) and growing degree days during (A) sowing to flowering and (B) sowing to physiological maturity of soybean at Jabalpur

At flowering stage, increase in GDD improved grain yield of soybean. Similarly, grain yield increases with an increase in GDD form sowing to physiological maturity stage. At flowering stage, around 900 °C day GDD is required whereas 1500-2000 °C day GDD is required from sowing to maturity of the crop for optimum yield. Hence, soybean sown at early date of sowing accumulates more heat units, which will be resulting in achieving higher grain yield, provided other factors (weed control, insect-pest control) and management practices are applied at recommended levels.

Sunflower

Solapur

Cultivars Bhanu(V_1), MSFH-17 (V_2) and Phule Raviraj (V_3) were exposed to three growing environments [sown on second fortnight of June (S_1), July (S_2) and August (S_3) 2015] to

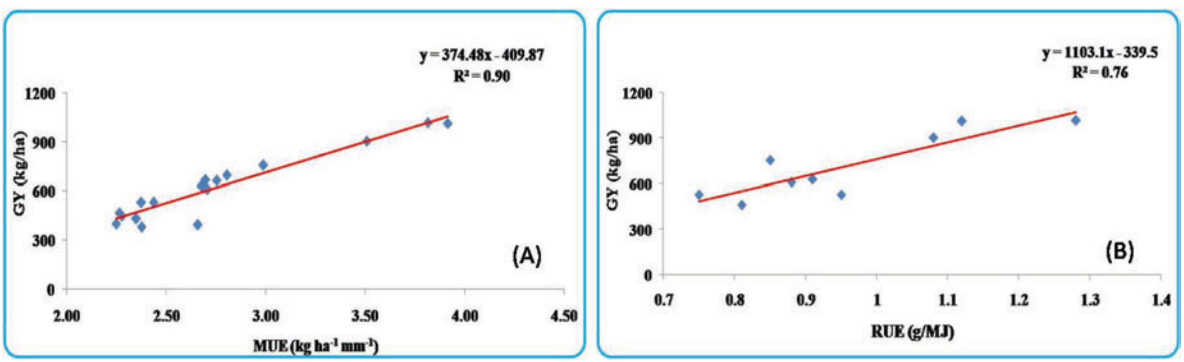


Fig.4.9 Relationship of sunflower grain yield with (A) moisture use efficiency and (B) radiation use efficiency (data pooled over *kharif* 2011-2015) at Solapur

study the crop weather relationships. Based on the pooled data during *kharif* 2011-2015, effect of cultivars and sowing time on grain yield, consumptive use of moisture and moisture use efficiency was studied and the results are presented in Fig. 4.9.

The moisture use efficiency (MUE) during total growth period of *kharif* sunflower showed a linear relationship with grain yield. The MUE of 2.50 to 3.00 kg ha^{-1} mm^{-1} was found to be optimum for getting higher grain yield. RUE and grain yield relationship [Fig. 4.7 (B)] also showed that radiation interception is in linear relationship with grain yield. The analysis indicated that if RUE increases from 1.1 to 1.2 g MJ^{-1}, it increases the yield from 0.6 to 1.1 t ha^{-1}. This indicated that for every increase of 0.1 g MJ^{-1} of solar energy use efficiency, there is an increase of 20 kg ha^{-1} in grain yield of sunflower.

Groundnut

Anand

Effect of soil moisture depletion during moisture sensitive stages of groundnut grown under three growing environments was studied. Groundnut cultivars M-335, GG-20 and GG-5 were sown on three dates, viz., onset of southwest monsoon (30 July 2015), 15 days after first sowing and 30 days after first sowing. The soil moisture depletion under different dates of sowing at 15 cm soil depth under different phenological phases of groundnut is depicted in Fig. 4.10.

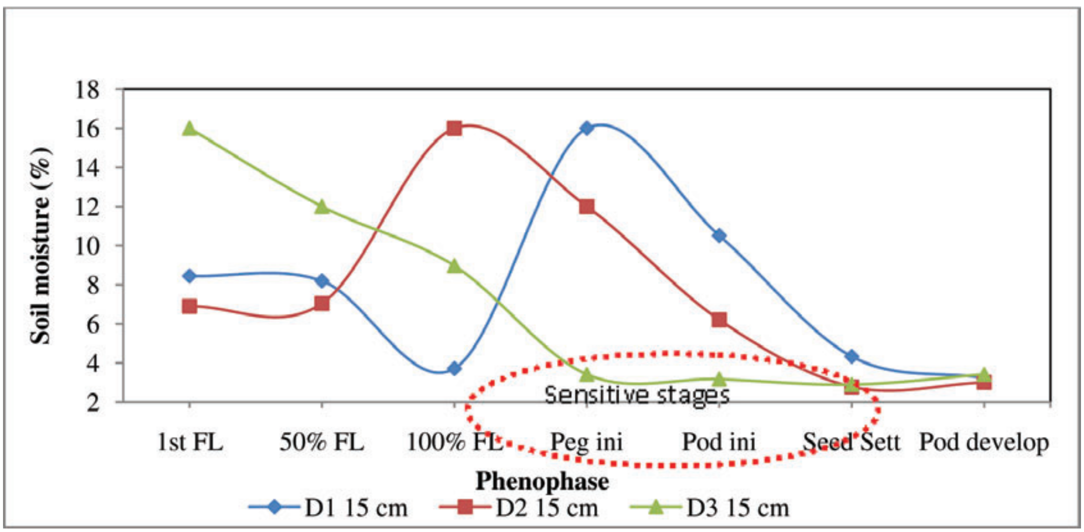


Fig. 4.10 Soil moisture status at different depths in different growth stages of groundnut cultivars grown under three growing environments at Anand.

Analysis indicated that during moisture sensitive stages of groundnut viz., 100% flowering, peg initiation and pod initiation, there was large variation of soil moisture depletion in all the dates of sowing. Highest moisture depletion during peg initiation to pod development was observed under crop sown on 29 August (D_3), as compared to other two sowings. The pod yield was also lowest (257 kg ha^{-1}) for crop sown on 29 August. The other two sowings recorded higher pod yield (1304 and 1090 kg ha^{-1} for D_1 and D_2, respectively).

Anantapur

A field experiment was undertaken to estimate phenophase-wise crop coefficients of groundnut. Split-plot design was used with the following treatments

Main plots : Dates of sowing	Sub plots - 50 mm Irrigation at
Early sowing – 2nd fortnight of July (08.07.2015)	0.6 IW/CPE ratio
Normal sowing – 2nd fortnight of July (25.07.2015)	0.8 IW/CPE ratio
Late sowing - 1st fortnight of August (13.08.2015)	1.0 IW/CPE ratio

Where, IW- irrigation water, CPE - cumulative pan evaporation

The results of the study is presented in Table 4.15

Table 4.15 Growth stage-wise crop coefficients for groundnut during three growing environments at Anantapur

Growth stage		IW/CPE=0.6			IW/CPE=0.8			IW/CPE=1		
	Kc									
	Days	8 July	25 July	13 Aug	8 July	25 July	13 Aug	8 July	25 July	13 Aug
Initial	25	0.24	0.37	0.36	0.25	0.38	0.36	0.24	0.36	0.38
Development	20	0.76	1.18	1.33	1.15	1.37	1.34	1.24	1.69	1.89
Mid	35	1.75	1.77	1.94	2.06	2.20	1.95	2.08	2.52	2.24
Late	15	1.44	1.23	0.85	1.96	1.38	1.52	1.73	1.49	1.29

Highest crop coefficient values were recorded during mid-season stage of the crop in all the dates of sowings and irrigation treatments. Crop sown on 25th July with a IW/CPE ratio of 1 recorded highest Kc value (2.52), followed by crop sown on 13th August (Kc - 2.24). The lowest Kc values at mid-season were recorded for IW/CPE ratio of 0.6, indicating that soil moisture stress affects the Kc values. In the initial stage, across all the sowing dates and irrigation treatments Kc varied from 0.24 to 0.38.

Cotton

Akola

Response of cotton genotypes [Tree cotton (*Gossypium arboreum*), Mexican cotton (*Gossypium hirsutum*) and *Bt* cotton] to environmental stress was studied using field experiment with factorial randomized block design. The treatments included:

Table 4.16 Canopy temperature(CT) and canopy temperature depression (CTD) as influenced by genotypes and planting density in cotton at Akola

Treatment	60 DAE		90 DAE		120 DAE	
	CT	CTD	CT	CTD	CT	CTD
Genotype						
AKH 081	30.5	2.5	27.7	4.9	32.6	4.2
AKA 7	30.0	3.0	27.1	5.5	32.4	4.4
Balwan	30.9	2.1	27.8	4.8	33.0	3.8
Planting density						
NP 100%	30.6	2.4	27.1	5.5	32.2	4.6
HDP 150%	30.1	2.9	27.3	5.3	32.5	4.3
HDP 200%	30.6	2.4	28.2	4.4	33.2	3.6

DAE – Days after Emergence

The mean CT and CTD values showed cyclic trend during 60 to 120 DAE stages of observation. The drop in CT values and maximum CTD observed at 90 DAE can be attributed to better hydration status of cotton plants as a consequence of 78.5 mm rainfall received on September 18, a period coinciding around this sage of observation. Canopy temperature at all the stages of observation was lowest in AKA-7(V_2) with high canopy temperature depression,indicating comparatively lower degree of field-scale plant water stress. i.e., among the genotypes, AKA-7 (*G arboreum*) showed more tolerance to environmental stress compared to others.

At 60 DAE, lowest CT and highest CTD was observed in high density planting at 150% population level. At 90 and 120 DAE, high density planting at 200% population level indicated maximum CT and lowest CTD. In a dense crop stand, competition for resources, particularly soil moisture, reduces share of each plant, thus reducing its hydration status, causing higher canopy temperature. Consequently, among the three genotypes, AKA-7 recorded the highest seed cotton yield (1715 kg ha^{-1}). In view of higher CTD at 90 and 120 DAE in NP100% treatment compared to other two treatments, planting density of 100% can be recommended.

Rabi 2015-16

Wheat

Hisar

Effect of growing environments and irrigation levels on radiation use efficiency was studied in wheat cultivar WH-1105. The crop was exposed to four growing environments (4^{th} and 20^{th} Nov; 5^{th} and 16^{th} Dec 2015) and four levels of irrigation (One at CRI stage only; CRI+heading; CRI+jointing+milk; CRI+jointing+anthesis+dough). The radiation use efficiency under different growing environments and irrigation levels at various phenophases were computed from the recorded dry matter accumulation and intercepted photosynthetically active radiation at each stage of the crop and the results are presented in Table 4.17.

Table 4.17: Effect of growing environments and levels of irrigation on radiation use efficiency (g MJ^{-1}) at various growth stages in wheat cultivar WH-1105 during *rabi* 2015-16 at Hisar

Treatments									
Growing Environments									
	CRI	**TL**	**JT**	**BT**	**HD**	**AN**	**ML**	**DS**	**PM**
D_1	0.22	0.35	0.72	1.36	1.66	1.95	2.36	2.54	2.44
D_2	0.22	0.32	0.69	1.34	1.60	1.85	2.28	2.33	2.22
D_3	0.21	0.34	0.69	1.23	1.43	1.69	1.98	2.13	2.18
D_4	0.20	0.28	0.63	1.12	1.24	1.38	1.78	2.04	2.18
Mean	0.21	0.32	0.68	1.26	1.48	1.72	2.10	2.26	2.25
S.D. (±)	0.01	0.03	0.04	0.11	0.18	0.25	0.27	0.22	0.12
C.V. (%)	0.03	0.09	0.06	0.09	0.12	0.14	0.12	0.09	0.05
Irrigation levels									
I_1	0.18	0.29	0.66	1.27	1.53	1.74	2.19	2.36	2.40
I_2	0.20	0.31	0.67	1.29	1.56	1.79	2.25	2.43	2.39
I_3	0.19	0.31	0.69	1.29	1.61	1.87	2.28	2.46	2.42
I_4	0.20	0.34	0.71	1.34	1.60	1.88	2.33	2.50	2.47
Mean	0.19	0.31	0.68	1.30	1.58	1.82	2.27	2.44	2.42
S.D.(±)	0.01	0.02	0.02	0.03	0.04	0.06	0.06	0.06	0.03
C.V. (%)	0.05	0.06	0.04	0.02	0.02	0.04	0.02	0.02	0.01

[CRI-Crown root initiation, TL- Tillering , JT- Jointing , BT- Booting,HD- Heading, AN – Anthesis, ML- Milk, DS- Dough stage, PM – Physiological maturity]

The results revealed that the higher radiation use efficiency was found at later stages as compared to initial stages of crop growth. Among different growing environments, the early sown crop recorded more radiation use efficiency at all the stages as compared to delayed sowing. In case of irrigation levels also, radiation use efficiency was found to be low under less irrigated and high under more irrigated conditions, at all the stages ofcrop.

Jammu

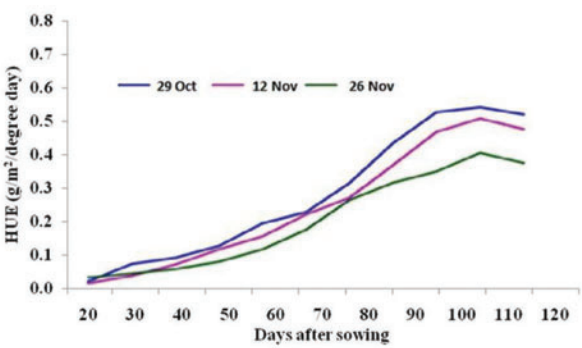
Effect of growing environments and cultivars on yield, yield attributes and heat use efficiency of wheat were studied. Three wheat cultivars, viz., HD-2967, Raj-3077 and RSP-561 were grown under three growing environments (sown on 29th Oct, 12th and 26th Nov 2015) and their effects on yield and yield attributes are presented in Table 4.18.

Table 4.18: Yield and yield attributing characters of wheat under different treatments during *rabi* 2015 -16 at Jammu.

Treatments	Seed yield (t ha^{-1})	Biomass (t ha^{-1})	Plant height (cm)	No. of tillers/ plant	No. of spike/ plant	No. of grains/ spike	Spike length (cm)	Test Wt. (g)
Growing environments								
29-10-2015 (Early)	4.6	13.1	108.1	5.7	5.2	41.6	9.8	43.5
12-11-2015 (Normal)	4.4	12.3	103.0	5.4	4.9	41.2	9.3	42.0
26-11-2015 (Late)	3.9	11.1	95.4	5.0	4.4	32.0	8.4	41.6
Mean	4.3	12.2	102.2	5.4	4.8	38.3	9.2	42.4
CD at 5%	0.46	0.38	2.99	0.68	0.24	7.3	0.78	NS
Cultivars								
HD-2967	4.1	11.4	98.7	5.6	4.7	39.9	8.6	43.3
Raj-3077	4.6	12.7	105.8	5.3	5.1	37.1	9.3	41.6
RSP-561	4.3	12.4	101.9	5.2	4.7	37.9	9.6	42.1
Mean	4.3	12.1	102.1	5.4	4.8	38.3	9.2	42.4
CD at 5%	NS	NS	2.99	NS	NS	NS	0.78	NS

The crop sown on 29th October recorded the highest grain yield (4.6 t ha^{-1}) and biomass (13.1 t ha^{-1}), which is statistically at par with normal sown (12th November) but significantly higher than the yield recorded in delayed sowing on 26th November. Growing environments showed significant effect on all the yield attributes, except test weight.

Among the different varieties, the highest grain yield was produced by Raj-3077 (4.6 t ha^{-1}) followed by RSP-561 (4.3 t ha^{-1}) and HD-2967 (4.1 t ha^{-1}). There was no significant difference among the three varieties in case of seed yield, biomass and yield attributes, except plant height and spike length.



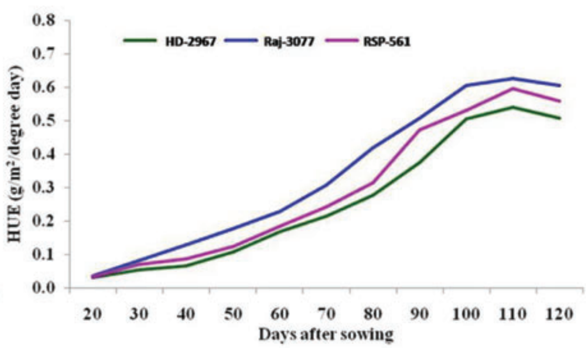


Fig. 4.11: Effect of (A) growing environments and (B) cultivars on heat use efficiency of wheat during *rabi* 2015-16 at Jammu

Heat use efficiency (g m^{-2} °C^{-1} day^{-1}) was worked out using accumulated dry matter and accumulated growing degree days at different days after sowing and the results are presented in Fig. 4.11.

The analysis indicated that heat use efficiency (HUE) was influenced by sowing environments as well as cultivars. HUE increased with age of the crop up to 105 days after sowing under early and normal sown conditions, whereas under late sown condition, it increased up to 110 days after sowing. The highest HUE was recorded in early sown crop (29th Oct) at all the growth stages, followed by HUE in normal sown (12 Nov) and delayed (26 Nov) sown conditions. The difference in HUE due to growing environments is highly visible in the reproductive stage (from 80-110 DAS). Among the varieties, Raj-3077 recorded highest HUE at all the days of observation, followed by RSP-561 and HD-2967, respectively.

Kanpur

Correlation coefficients between yield and weather parameters (Tmax, Tmin, soil temperature, rainfall, heat unit, relative humidity and duration of crop) were worked out for developing step wise regression equations for predicting grain yield and biomass of wheat. The equations developed are presented in Table 4.19.

Table 4.19: Step-wise regression equations developed for prediction of grain yield and biomass of wheat during *rabi* 2015-16 at Kanpur

Parameters	Equation	R^2
Grain yield (kg ha^{-1})	Y= 47.25 + 5.14 Tmax. P_2 - 0.06Tmin. P_2 -7.14 Soil T. P_2	0.86
	Y= 63.26 + 2.37 Tmax. P_3 - 0.37Tmin. P_3 -3.89 Soil T. P_3	0.84
	Y= 89.06 - 0.31 Tmax. P_4 – 1.15Tmin. P_4 -0.83 Soil T. P_4	0.83
	Y= 11.29 + 0.33 RF. P_4 – 0.03GDD. P_4 +1.69 RH. $P_{4=}$ - 0.32 dura.	0.85
Boimass(q ha^{-1})	Y= 213.10 – 10.17 Tmax. P_2 – 1.10Tmin. P_2 +8.09 Soil T. P_2	0.93
	Y= 44.96 + 10.74 Tmax. P_3 – 13.80Tmin. P_3 -2.19 Soil T. P_3	0.92
	Y= 268.51 + 1.42 Tmax. P_4 + 11.98Tmin. P_4 -14.83 Soil T. P_4	0.93
	Y= -28.69 + 1.12 RF. P_4 – 0.01GDD. P_4 +0.02 RH. $P_{4=}$ + 0.07 dura.	0.95

[P_2 = Tillering to PI, P_3 = PI to Anthesis, P_4 = Anthesis to Maturity]

Regression coefficients of different variables and coefficient of determination (R^2) of models for grain yield and biomass at different stages showed that minimum and soil temperature had significant adverse effect on grain yield. The regression equations accounted for 86, 84 and 83 per cent variation in yield due to weather parameters during P_2, P_3 and P_4 stages.

Ludhiana

Field experimental data on crop weather relations generated during rabi 2009-10 to 2012-13 on four cultivars, viz., PBW-550, DBW-17, PBW-343 and PBW 621 were analyzed for identifying critical growth stages and the average weather parameters during different growth stages, favourable for obtaining higher yield (4.6-5.0 t ha^{-1} across the varieties) in wheat. The results of the analysis are presented in Table 4.20.

Table 4.20: Meteorological parameters favourable for high wheat yield (*rabi* 2009-10 to 2012-13) at Ludhiana

Crop stage	Duration (Days)	Temperature (°C)		Relative humidity (%)		Sunshine hours (Hr)	Rainfall (mm)
		Tmax	Tmin	Maximum	Minimum		
CRI	25-35	25	9.5	94	45	6	11
Tillering	30-35	24.5	11.2	93.5	46.5	5.7	14
Booting	10-17	23.5	7.5	94.5	55	5.5	60
Anthesis	7-15	20.5	8.5	94.5	55	5.5	90
Milk	15-30	22	8	95	53.5	5.7	91
Hard dough	7-15	22.5	10	92.5	50	6	90
Maturity	5-10	23	9	90	50	6.5	10

It was found from the analysis that maximum temperature of 25 °C and minimum temperature of 9.5 °C from sowing to CRI stage (25-35 days) are optimum for obtaining higher yield. Similarly, maximum temperature range 20.5-23 °C and minimum temperature of 8-10 °C during different post-anthesis stages are optimum temperature ranges for high yield in wheat.

Palampur

Experimental data of wheat during *rabi* 2011-12 to 2015-16 were pooled and relationship between mean temperature during vegetative and reproductive phases with grain yield was studied and the results are presented in Table 4.21.

Table 4.21: Mean temperature during vegetative and reproductive phases for highest productivity during past five years in irrigated wheat at Palampur

Year	Temperature (°C)	Vegetative (°C)	Reproductive (°C)	Yield (kg/ha)
2011-12	Maximum	19.6	26.2	2091
	Minimum	7.6	13.6	
2012-13	Maximum	17.4	24.8	2771
	Minimum	5.5	12.3	
2013-14	Maximum	16.9	21.0	4357
	Minimum	4.8	9.6	
2014-15	Maximum	17.1	21.9	2102
	Minimum	4.8	11.4	

2015-16	Maximum	18.0	23.9	3063
	Minimum	4.9	11.3	

The analysis indicated that

- During the year 2013, highest wheat yields were obtained. This may be due to lowest observed Tmax (16.9, 21 °C) & Tmin (4.8, 9.6 °C) during vegetative and reproductive phases.
- Similarly, in the year with lowest yield, the crop experienced highest maximum (19.6, 26.2 °C) and minimum temperature (7.6, 13.6 °C) in both vegetative and reproductive stages among all the five years.
- During 2014-15, though the temperatures were within the threshold limits, the yield was low due to excess rainfall (661.3 mm) in 11 rainy days, which created water logged condition in several low-lying irrigated areas of the state, affecting the yield.

Raipur

Cultivars Kanchan, HD-2967 and CG-1013 were grown under three growing environments (sown on 15th and 30th Nov and 15th Dec 2015) to study the crop weather relationships. The effect of cultivars and growing environments on heat and radiation use efficiencies was studied and the results are presented in Table 4.22 A and B.

Table 4.22(A): Heat use efficiency (g m^{-2} $^{o}day^{-1}$) of wheat varieties as influenced by different growing environments at Raipur

Varieties	15 Nov	30 Nov	15 Dec	MEAN
Kanchan	0.68	0.65	0.74	0.69
HD 2967	0.58	0.63	0.45	0.55
CG 1013	0.51	0.61	0.63	0.58
Mean	0.59	0.63	0.61	

Kanchan recorded the highest HUE among the three wheat cultivars studied, followed by CG-1013. Highest HUE was observed in Kanchan sown on15th Dec, followed by 15th Nov and 30th Nov sown crop. HUE of Kanchan and CG 1013 was highest during third sowing, but for HD 2967, highest HUE was observed during second sowing.

Table 4.22 (B): Radiation use efficiency (gm^{-2} MJ^{-1}) of wheat varieties as influenced by different growing environments at Raipur

Varieties	15 Nov	30 Nov	15 Dec	MEAN
V1 Kanchan	1.63	1.56	2.10	1.74
V2 HD 2967	1.39	1.75	1.25	1.46
V3 CG 1013	1.19	1.62	1.78	1.50
Mean	1.40	1.64	1.69	

Highest RUE was recorded in Kanchan, followed by CG 1013 and HD 2967. For the crop sown during 30th Nov, HD-2967 recorded highest RUE. For the crop sown on 15th Dec, the RUE of Kanchan was significantly higher compared to that of CG 1013 and HD 2967.

Ranchi

Effect of growing environments and wheat cultivars on grain yield, heat and radiation use efficiencies was studied at Ranchi center. Cultivars HUW468, K9107 and Birsa Genhu 3 were exposed to three growing environments (sown on 5th Nov, 5th and 20th Dec 2015) and heat and radiation use efficiencies were calculated and the results are presented in Table 4.23.

Table 4.23: Heat (HUE) and Radiation (RUE) Use Efficiency of wheat cultivars under different thermal regimes at Ranchi

Sowing Date	Variety	HUE (kg ha^{-1} °day^{-1})	RUE (kg ha^{-1} MJ^{-1})	Yield (kg ha^{-1})
20 Nov	HUW 468	2.6	2.1	4026
	K9107	2.2	1.8	3508
	BG 3	2.9	2.3	4502
5 Dec	HUW 468	2.4	1.9	3675
	K9107	2.0	1.6	3224
	BG 3	2.5	2.1	3954
20 Dec	HUW 468	2.4	2.0	3639
	K9107	1.8	1.5	2946
	BG 3	2.3	1.9	3579

Heat and radiation use efficiencies in comparison with grain yield of wheat (Table 4.23) showed that early sown crop varieties registered higher HUE and RUE, compared to the late sown crop varieties. Among the varieties BG 3 achieved highest heat use efficiency (2.9 kg ha^{-1} °day^{-1}) and highest radiation (2.6 kg ha^{-1} MJ^{-1}) use efficiencies under early sowing. The higher heat and radiation use efficiencies in BG 3 incase of early sowing was also reflected in its higher yield, compared to other varieties. However, under delayed sowing (20 Oct), the cultivar HW 468 not only registered higher HUE and RUE, but also achieved higher yield compared to other varieties.

The relationship between HUE and RUE with grain yield was also attempted, which revealed that both showed positive linear relationship, with higher correlation coefficients (Fig. 4.12).

Samastipur

The pooled data of wheat crop from 2011-16 was used to develop optimum requirements of maximum and minimum temperatures during different phenological stages of wheat for realization of different yield levels. The experimental yields were categorized into different yield groups and for each yield group, optimum requirements of maximum and minimum

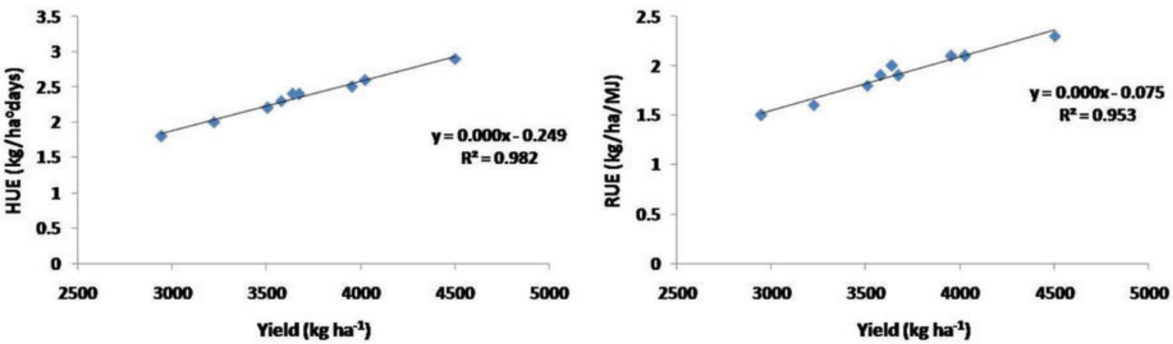


Fig. 4.12: Relationship of HUE and RUE with grain yield of wheat during *rabi* 2015-16 at Ranchi

temperatures were worked out and the results are presented in Table 4.24.

Table 4.24: Optimum requirements of maximum and minimum temperatures during different phenological stages of wheat for realization of different yield levels at Samastipur

Yield levels (kg ha^{-1})	Sowing to tiller initiation		50% flowering to milk		50% flowering to maturity	
	Max T (°C)	MinT (°C)	Max T (°C)	MinT (°C)	Max T (°C)	MinT (°C)
< 2000	22.6	7.6	30.2	16.8	33.1	18.0
> 2000 and < 3000	24.0	9.2	29.4	15.1	32.1	17.2
> 3000 and < 4000	22.5	9.8	26.9	13.1	30.4	15.7
> 4000	23.7	11.8	24.6	11.6	29.2	14.4

It was observed that temperatures played significant role in realizing better yield. Maximum temperatures above 30.2 and 33.1 °C during 50% flowering to milk and 50 % flowering to maturity, respectively reduced grain yield below 2000 kg/ha. Similarly, minimum temperature of 16.8 and 18.0 °C during 50 % flowering to milk and 50 % flowering to maturity had deleterious effect on yield. As the region is prone to dry westerly wind, which prevails during the flowering to maturity period of wheat, maximum temperature plays crucial role in non-setting of wheat grains. Maximum temperature above 25 °C during 50% flowering to milk stage, tends to reduce the grain yield below 4000 kg/ha. During 50% flowering to maturity stage, maximum and minimum temperatures should not be above 29.2 and 14.4°C respectively, for achieving yield above 4000 kg/ha. An increase of maximum temperature from 29.2 to 33.1 °C during flowering to maturity stage in this region curtails the wheat production significantly.

Rabi Maize

Kovilpatti

Effect of growing environments and cultivars on grain yield, stover yield, heat use efficiency and BC ratio was studied by Kovilpatti center. Maize hybrids S-6850, NK-6240, RMH-3033 and COH (M) 6 were exposed to four growing environments (sown on 39, 40, 41 and 42 SMW) and the results are presented in Table 4.25.

Table 4.25: **Effect of growing environments and cultivars on grain yield, stover yield, heat use efficiency in *rabi* maize at Kovilpatti**

Treatments	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Heat use efficiency (kg ha^{-1} °day^{-1})	Seasonal rainfall (mm)
39	5824	10607	3.52	498
40	5528	10066	3.34	472
41	4891	8907	3.00	411
42	4811	8759	2.84	410
Hybrids				
S 6850	4576	8334	2.14	
NK 6240	5670	10325	3.14	
RMH 3033	4882	8891	2.96	
COH (M) 6	5926	10790	3.22	

Highest grain yield (5824 kg/ha) and stover yield (10607 kg/ha) were recorded by crop sown during 39 SMW, followed by crop sown during 40 SMW,because of higher rainfall during the crop season. Among hybrids, COH (M) 6 recorded highest grain and stover yield, followed by NK 6240. Higher heat use efficiency was recorded under 39th standard week sown crop (3.52kg/ha/°C day). Higher heat use efficiency was registered by COH (M) 6 hybrid (3.22kg/ha/°C day).

Rabi sorghum

Solapur

To study the crop-weather relationship in rabi sorghum, three cultivars (M-35-1, Mauli and Yeshoda) were cultivated under three growing environments (sown during 36, 38, 40 and 42 SMW). Pooled experimental data during kharif 2011-2015 were used for the analysis and the relationship of seasonal maximum temperature and minimum temperature with grain yield was studied and the results are presented in Fig. 4.13 (A) and (B).

Maximum and minimum temperature during growing period of the crop showed quadratic relationship with grain yield. The analysis showed that seasonal maximum temperature greater than 32.2 °C and minimum temperature greater than 18 °C caused reduction in the

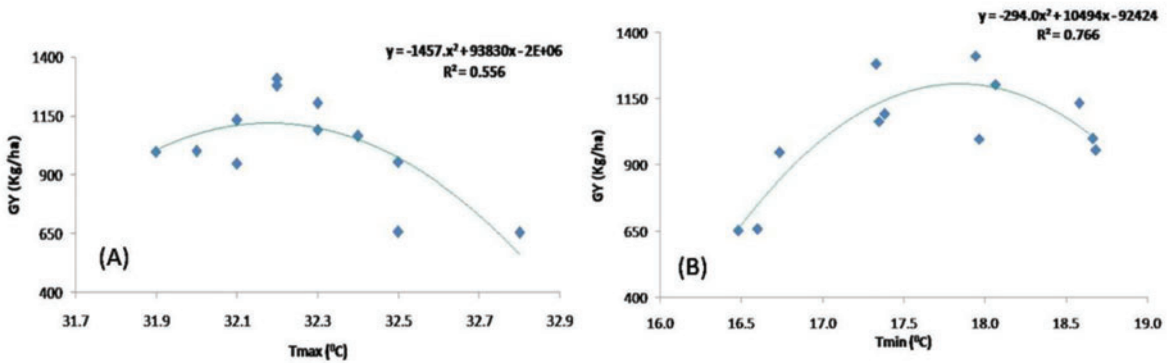


Fig. 4.13: Relationship of *rabi* sorghum grain yield with (A) maximum temperature (B) minimum temperature (pooled data during *kharif* 2011-2015) at Solapur

grain yield. So, optimum temperatures were identified as optimum thermal conditions for obtaining higher yield of rabi sorghum.

Chickpea

Akola

Effect of growing environments and different cultivars on heat use efficiency (HUE) was studied at Akola. Three cultivars (JAKI-9218, Chaffa-816 and Vijay were exposed to three growing environments (sown during 40, 41 and 42 SMW). The HUE estimated with respect to both biomass and grain yield indicated marginal difference among different sowings.Highest HUE in terms of seed yield (0.45 kg ha^{-1} °$Cday^{-1}$) under 41 SMW sowing and with respect to biomass (1.15 kg ha^{-1} °$Cday^{-1}$) was observed under 40 SMW sowing (Table 4.26).Amongst the varieties, heat use efficiency with respect to seed yield (0.47 kg ha^{-1} °$Cday^{-1}$) was maximum in JAKI-9218 and biomass production (1.18 kg ha^{-1} °$Cday^{-1}$) was higher in Chaffa-816.

Table 4.26: Heat use efficiency of chickpea varieties in terms of seed and biomass production (kg ha^{-1} °C day^{-1}) under different dates of sowing (Values in bold indicated HUE in terms of biomass) at Akola

Varieties	Sowing date			
	D_1 - 40 MW (06.10.15)	D_2 -41 MW (13.10.15)	D_3 - 42 MW (21.10.15)	Mean
V_1 - JAKI-9218	0.45	0.48	0.46	0.47
	1.12	**1.12**	**1.15**	**1.13**
V_2 – Chaffa 816	0.41	0.44	0.44	0.43
	1.13	**1.22**	**1.20**	**1.18**
V_3 – Vijay	0.37	0.42	0.39	0.39

	1.20	**1.05**	**0.98**	**1.07**
Mean	0.41	0.45	0.43	
	1.15	**1.13**	**1.11**	

Jabalpur

Crop weather relationship in chick pea were studied by growing chickpea cultivars JGK-1, 3 (Kabuli types), JG-315, 322, 74 and 11 (Desi types) and JGG-1 (Gulabi type) under three growing environments (21st Nov; 5th and 20th Dec 2015). Correlation study (Pearson's correlation coefficient) between weather parameters and seed yield was conducted at different phenological stages of the crop. The results are presented in Table 4.27.

Table 4.27: Pearson's correlation coefficient between seed yield and weather parameters at different phenological stages in chickpea at Jabalpur

Phenological stages	MaxT	MinT	Sunshine Hours (hours)	GDD (^{0}Cday)	HTU (^{0}C day hr)	PTU (°C day hr)	RH\M (%)	RHe (%)	Rainfall (mm)	Rainy days
Branching (50%)	0.25	0.25	-0.28	0.30	-0.06	0.30	-0.02	0.27	-	-
Flowering initiation	0.16	0.26	-0.39	-0.03	-0.12	-0.04	-0.03	-0.01	-0.07	-0.74
Pod formation	0.21	0.22	-0.03	0.19	0.20	0.13	-0.21	-0.07	0.19	0.19
Physiological maturity	-0.31	-0.26	-0.36	-0.35	-.564**	-.468*	0.39	0.29	-0.15	-0.19
Harvest	-0.32	-0.22	-0.39	-0.22	-.554**	-0.37	0.42	0.42	-0.27	-0.27

***. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed).*

It was a two-tailed correlation tested in SPSS software. The results suggests that both the temperatures were positively correlated with grain yield at all the stages, except during pod initiation to physiological maturity. Similarly sunshine hours were negatively associated with seed yield, but correlations were not significant. The relative humidity at flowering and pod formation stageswas negatively associated with yield. Beside this, rainfall was also negatively associated at maturity stage. The HTU and PTU from pod initiation to physiological maturity showed highly significant relationship with yield, thus indicating the negative impact of long days and high temperature during that stage on yield.

Green gram

Kovilpatti

Green gram cultivars Co (Gg) 7, Co 8, VBN (Gg) 2 and KM 2241 were grown under three sowing conditions (39, 40 and 41 SMW) to study the crop-weather relationships. Correlation of weather parameters with yield indicated that maximum temperature during germination, vegetative and pod development stages had significant positive correlation (0.67*, 0.62* & 0.61, respectively) and minimum temperature during vegetative, pod initiation and pod development stage had significant positive correlation (0.65*, 0.62*, 0.60*, respectively) with grain yield (Table 4.28). Sunshine hours during germination and vegetative stages had significant positive relationship with yield.

Table 4.28: Correlation coefficient value at different phenophases of green gram at Kovilpatti

Phenophase	Weather parameters/ agrometeorological indices					
	Max. T	Min. T	BSS	RH	ET	RF
Germination stage	0.667*	-0.042	0.663*	-0.556	0.662*	0.408
Vegetative stage	0.617*	0.652*	0.589*	-0.538	0.557	-0.445
50% flowering stage	0.291	0.257	-0.594*	-0.469	0.531	0.049
50% Pod initiation stage	-0.023	0.619*	-0.354	0.399	-0.191	-0.091
Pod development stage	0.607*	0.602*	0.313	-0.617*	0.529	-0.130
Maturity stage	0.011	0.452	-0.191	0.370	-0.205	0.197

* *Significant at 0.05 level*

Mustard

Faizabad

Influence of cultivars and growing environments on thermal use efficiency of mustard was studied using three cultivars (Varuna, NDRS-2001-1 and NDR-850) grown under three growing environments (30th Oct, 14th Nov and 29th Nov 2015). Thermal use efficiency (g/m^2/°days) of mustard at different phenophases is presented in Table 4.29.

Table 4.29: Thermal use efficiency (g/m^{-2}/°days) of mustard as affected by growing environments and varieties at Faizabad

Treatments	Thermal use efficiency (g/m^2/^{0}days)						
	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	105 DAS	At harvest
Growing Environment							
30 Oct.	0.12	0.15	0.26	0.40	0.52	0.64	0.63
14 Nov.	0.10	0.15	0.27	0.35	0.52	0.56	0.62
29 Nov.	0.12	0.16	0.20	0.39	0.49	0.54	0.54
Varieties							
Varuna	0.11	0.17	0.20	0.41	0.54	0.54	0.60
NDRS-2001-1	0.12	0.15	0.18	0.36	0.46	0.49	0.54
NDR- 8501	0.14	0.13	0.20	0.42	0.52	0.55	0.62

Highest TUE at harvest was recorded (0.63 g/m²/°days) for crop sown on 30th Oct, and the lowest (0.54 g/m²/°days) for the crop sown on 29th Nov. Different varieties had marked influence on the thermal use efficiency of mustard at all phenophases. Maximum thermal use efficiency (0.62 g/m²/°days) from sowing to maturity was recorded in NDR-8501 variety, while minimum thermal use efficiency from sowing to maturity was obtained in NDRS Variety (0.54g/m²/°days) of mustard.

Hisar

Energy balance studies were conducted at Hisar with five genotypes (Laxmi, RH 0749,Kranti, RH 406 and RH 30) grown under three growing environments (7th, 20th Oct and 3rd Nov 2015). Diurnal observations of energy balance at maximum LAI stage, flowering and pod formation stage over mustard varieties viz., RH-30, RH-406, Laxmi, Kranti and RH 0749 were recorded in the crop sown on normal date, along with observations over the bare field. The diurnal energy balance components recorded on a clear day on different dates have been depicted in Fig. 4.14. In general, around 25 to 85 per cent of net radiation was used as latent heat for evaporation (LE) at different phenophases. Values of LE varied with the crop growth stages. The maximum values of LE were recorded at maximum leaf area index stage compared to flowering and pod formation stage, mainly due to increase in accumulation of biomass as well as LAI. The sensible heat flux was lesser than LE, irrespective of the sowing dates and date of observation. Among the varieties, RH 0749 used higher fraction of net radiation for LE because of its denser and greener canopy with erect leaf structure, compared to other varieties

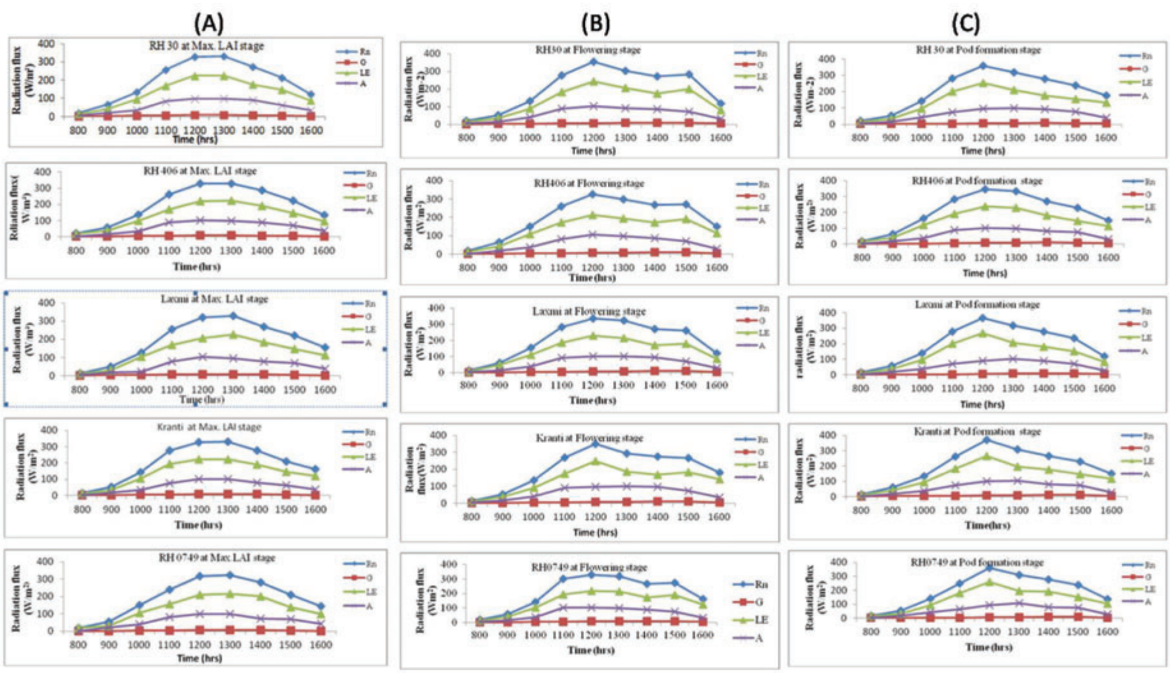


Fig. 4.14: Energy balance components at (A) maximum leaf area index stage; (B) flowering stage and (C) pod formation stage in different mustard varieties during *rabi* 2015-16 at Hisar

Potato

Jorhat

Monitoring of crop stress was undertaken in potato at Jorhat center using canopy-air temperature difference (CATD). Three cultivars viz., Kufri-Jyoti, Kufri-Pokhraj and local variety were exposed to three growing environments (sown on 19th Nov, 7th Dec and 23rd Dec 2015) and periodic observations on canopy and air temperature were taken using infra-red thermometer. The results of the study are presented in Fig. 4.15 A, B and C.

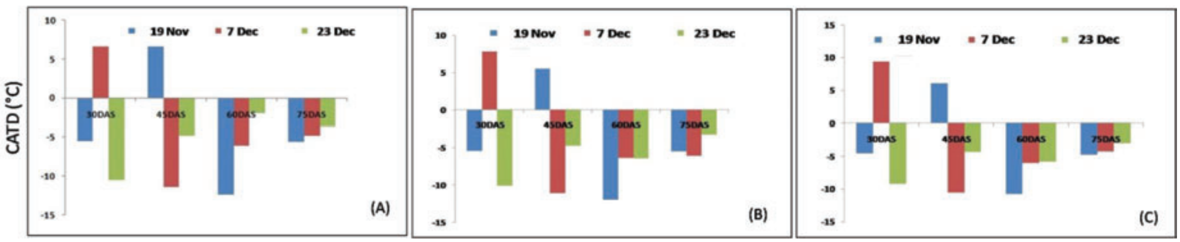


Fig.4.15: CATD at different growth stages of potato cultivars (A) Kufri Jaya; (B) Kufri Pokhraj and (C) Local variety during *rabi* 2015-16 at Jorhat

Early and normal sown crop suffered from Water Stress during early vegetative growth, compared to late sown crops as revealed by the positive CATD values. Stress free days with more negative CATD values were observed during 44-60 days after sowing in all the three cultivars. In the case of tuber yield, KufriJyoti performed best in 2nd (20.8 t ha^{-1}) and 3rd sowing (12t ha^{-1}), while Kufri Pokhraj performed best under 1st date of sowing (34.25 t ha^{-1}), due to lesser moisture stress during 45-75 days after sowing in the respective sowing dates and varieties.

Mohanpur

A field experiment with potato cultivar Kufri Jyoti was conducted with three growing environments [planted on 15th Nov (D_1), 29th Nov (D_2) and 13th Dec 2015 (D_3)] and three irrigation levels [all furrow irrigation (M_1), alternate furrow irrigation (M_2) and paired furrow irrigation (M_3)] to study the crop weather relationships. Seasonal evapotranspiration (SET) was estimated and water use efficiency was worked out and is presented in Table 4.30.

Table 4.30: Impact of date of planting and irrigation methods on tuber yield (Mg ha^{-1}) of Potato at Mohanpur

Treatment combinations	2012-13			2013-14		
	SET	Yield	WUE	SET	Yield	WUE
D_1M_1	268.3	31.2	11.6	270.0	28.5	10.5
D_1M_2	209.8	26.0	12.4	212.3	24.1	11.4
D_1M_3	207.2	24.1	11.6	208.4	23.1	11.1
D_2M_1	273.8	24.3	8.9	266.1	23.2	8.7

D_2M_2	211.2	22.2	10.5	205.4	22.3	10.9
D_2M_3	209.4	20.0	9.6	201.2	21.7	10.8
D_3M_1	270.0	23.7	8.8	250.6	23.9	9.6
D_3M_2	206.5	21.1	10.2	190.6	21.2	11.1
D_3M_3	203.9	21.1	10.4	186.3	20.2	10.8

Irrespective of irrigation method, the highest SET (231.5 mm) was observed under two weeks delayed planting (D_2). Under normal (D_1) and four weeks (D_3) delay in planting SET value reduced by only 3.6 and 1.8 mm respectively. Irrespective of date of planting the highest SET (270 mm) was recorded under all furrow irrigation, which reduced by 62 and 64 mm under alternate and paired furrow irrigation treatments, respectively. During second experimental year, the reduction was to the tune of 60 and 64 mm under alternate and paired furrow irrigation treatments, respectively.

During both the years, highest water use efficiency was achieved under normal date of planting condition (11.9 and 11.0 Kg m^{-3} for 2012-13 and 2013-14 respectively). Delayed planting reduced the WUE due to reduction in tuber yield. Among the methods of irrigation, alternate furrow irrigation recorded maximum WUE for both the years, followed by paired furrow irrigation. All furrow irrigation resulted in lowest WUE values during the crop growing seasons.

Further, the relationship between SET and tuber yield was studied for the both the seasons and the results are presented in Fig.4.16.

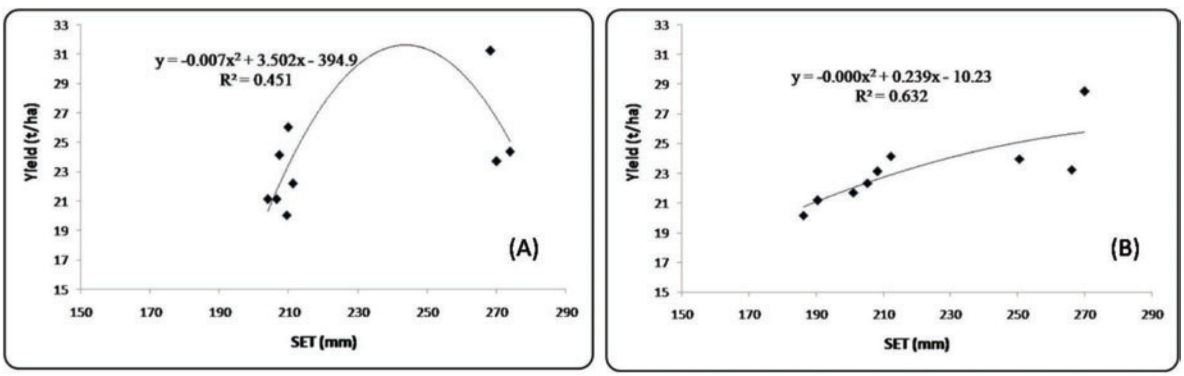


Fig.4.16: Relationship between tuber yield and seasonal ET of potato during (A) 2012-13 and (B) 2013-14 at Mohanpur

Quadratic relationship existed between SET and yield for both the years. SET alone can explain yield by 45 and 63% respectively for both the years (Fig. 4.15). In general the maximum yield obtained when SET value remained around 250 mm. afterwards a tendency to reduction in yield was observed which indicated more water application may hamper the tuber bulking process.

Horticulture crops

Grape

Vijayapura

Crop-weather relationship studies were taken up in orchards of five selected farmers from the village Jumanal falling under Vijayapura center. All the five farmers are growing Thompson seedless cultivar. Effect of fog on grapes was studied. Farmers had taken up pruning on 25th October 2015. However, there was fog in the village for about 10-11 days after pruning. Rain and fog are detrimental to the crop, as it is at the delicate flower bud stage. Considerable flower drop was noticed due to the foggy condition. From the daily data for the period 1st to 7th Nov 2015, which corresponds to 7 to 13 days after pruning, it was noticed that there was increase in morning vapor pressure by 3.6 mmHg on 3rd and further by 0.6 mm Hg on 4th November (Table 4.31). Similarly, percent increase in morning relative humidity increased by sixteen percent on 3rd and further by six percent on 4th, which might have caused fog formation on 3rd /4th November 2015, which corresponded to 10 days after pruning.

Table 4.31: Daily weather parameters during first week of Nov. 2015 at RARS, Vijayapura

Date	Tmax	Tmin	VP1	VP2	RH1	RH2	BSS	RF
	(°C)	(°C)	mm Hg	mm Hg	(%)	(%)	(h)	(mm)
01-11-15	32.4	20.4	15.1	13.9	74	40	2.5	0.0
02-11-15	33.0	19.5	12.9	14.2	67	42	8.4	0.0
03-11-15	32.2	19.8	16.5	14.0	83	39	2.5	0.0
04-11-15*	33.0	19.5	17.1	15.2	89	44	7.3	0.0
05-11-15	33.2	19.5	14.5	14.7	71	43	8.2	0.0
06-11-15	33.4	20.5	15.8	10.8	69	30	7.8	0.0
07-11-15	33.0	19.4	13.3	11.9	67	35	8.6	0.0

**: Fog was noticed in the morning hours in the village*

Mango

Bangalore

Climatic water balance studies were conducted in mango orchard to study the impact of soil moisture on mango yield and the results are presented in Fig. 4.17.

Out of 1070.5 mm rainfall, 994.4 mm (including previous year's left over moisture) of rain water were used for evapotranspiration by Mango against the requirement of 1345.9 mm.

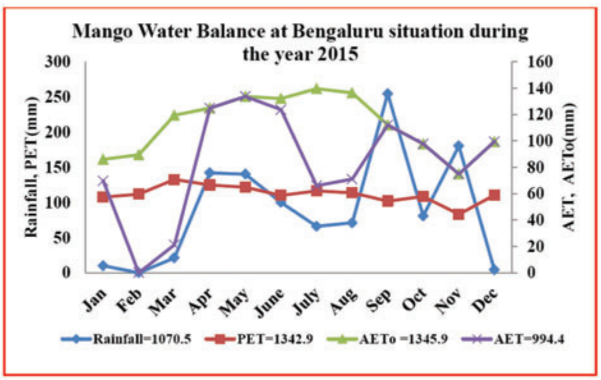


Fig. 4.17: Monthly climatic water balance for mango during 2015 at Bangalore

5. Crop Growth Modelling

Kharif

Akola

Soybean

CROPGRO model (DSSAT v 4.5) was calibrated and validated for three soybean varieties viz. JS-335, JS-9305 and TAMS 98-21. The genetic coefficients were determined by incorporating experimental data into the GLUE coefficient estimator embedded in the DSSAT v 4.5 model. Model was evaluated for different phenological stages. The observed and predicted mean number of days for anthesis were 39 and 39; 39 and 39; and 40 and 41 for the varieties JS-335, JS-9305 and TAMS 98-21, respectively. The Root Mean Square Error (RMSE) was 1.66, 1.22 and 1.22, respectively for JS-335, JS-9305 and TAMS 98-21 across different sowing treatments (Table.5.1).

Table. 5.1: Error per cent for simulated days to anthesis, first pod, first seed and physiological maturity from the observed data on phenology-2015 at Akola

Cultivar/Date of sowing	Anthesis day			First pod day			First seed day			Physiological maturity		
	O	S	Error %	O	S	Error %	O	S	Error %	O	S	Error %
JS-335												
D_1 - 28 SMW	42	40	-5.00	53	50	-6.00	64	65	1.54	87	92	5.43
D_2 - 29 SMW	39	39	0.00	50	50	0.00	62	63	1.59	84	87	3.45
D_3 - 30 SMW	38	38	0.00	48	49	2.04	60	61	1.64	81	83	2.41
D_4 - 31 SMW	36	37	2.70	46	47	2.13	57	59	3.39	77	80	3.75
Mean	39	39	-0.57	49	49	-0.46	61	62	2.04	85	86	3.76
SD			3.21			3.82			0.90			1.26
RMSE			1.12			1.66			1.32			3.43
PE			2.89			3.77			2.18			4.17
D			1.00			1.00			1.00			1.00
JS-9305												
D_1 - 28 SMW	42	40	-5.00	53	50	-6.00	64	63	-1.59	87	86	-1.16
D_2 - 29 SMW	39	39	0.00	50	49	-2.04	61	61	0.00	82	82	0.00
D_3 - 30 SMW	37	38	2.63	48	48	0.00	59	59	0.00	79	78	-1.28
D_4- 31 SMW	36	37	2.70	45	47	4.26	56	57	1.75	76	75	-1.33
Mean	39	39	0.08	49	49	-0.95	60	60	0.04	81	80	-0.94
SD			3.61			4.27			1.37			0.63

RMSE			1.22			1.87			0.71			0.87
PE			3.18			3.82			1.18			1.07
D			1.00			1.00			0.99			1.00
TAMS 98-21												
D_1 - 28 SMW	44	44	0.00	56	60	6.67	68	69	1.45	91	95	4.21
D_2 - 29 SMW	41	42	2.38	53	58	8.62	65	65	0.00	88	89	1.12
D_3 - 30 SMW	38	40	5.00	49	54	9.26	61	62	1.61	82	84	2.38
D_4- 31 SMW	38	39	2.56	49	52	5.77	59	59	0.00	79	80	1.25
Mean	40	41	2.49	52	56	7.58	63	64	0.77	85	87	2.24
SD			2.04			1.63			0.89			1.43
RMSE			1.22			4.33			0.71			2.35
PE			3.04			8.37			1.12			2.76
D			1.00			0.99			1.00			1.00

The observed and predicted mean number of days for physiological maturity were 85 and 86; 81 and 80; and 85 and 87 for the varieties JS-335, JS-9305 and TAMS 98-21, respectively. The RSME values for the varieties JS-335, JS-9305 and TAMS 98-21, were observed as 3.43, 0.87 and 2.35, respectively. The observed and predicted mean seed yield of the varieties JS-335, JS-9305 and TAMS 98-21 across different sowing treatments are 580 and 584; 615 and 603; and 526 and 525, respectively. The degree of agreement (D-stat) was 0.99 which shows a good agreement between observed and simulated seed yield.

After calibration and validation, the model was applied for simulating the conditions of 2015 and application of irrigation at critical stages for understanding the benefits of irrigation (Table.5.2).

Table 5.2: Effect of environmental modification in the form of irrigation application on soybean seed yield during *kharif* 2015 at Akola

Sowing date	Seed yield (kg/ha)			
	Observed (rainfed)	Simulated (protective irrigation)		
		1 irrigation (August 27)	1 irrigation (Sep 28)	2 irrigations (Aug 27-Sep 28)
		JS-335		
D_1 (28 SMW)	842	1075 (+28) (FL)	981 (+17) (LSD)	1469 (+74)
D_2 (29 SMW)	707	768 (+9) (FL-IN)	1024 (+45) (PF-SF)	1183 (+67)

D_3 (30 SMW)	496	507 (+2) (MVG)	901 (+82) (PF)	957 (+93)
D_4 (31 SMW)	290	289 (+0.3) (EVG)	725 (+150) (PF)	732 +(152)
JS-9305				
D_1 (28 SMW)	766	1105 (+44) (FL)	841 (+10) (LSD)	1356 (+77)
D_2 (29 SMW)	757	820 (+8) (FL-IN)	964 (+27) (PF-SF)	1173 (+55)
D_3 (30 SMW)	552	557 (+1) (MVG)	921 (+67) (PF)	976 (+77)
D_4 (31 SMW)	337	338 (+0.3) (EVG)	787 (+134) (PF)	793 (+135)
TAMS 98-21				
D_1 (28 SMW)	739	873 (+18) (L-VG)	1264 (+71) (SD)	1544 (+109)
D_2 (29 SMW)	562	631 (+12) (ML-VG)	1092 (+94) (PF-SF)	1221 (+117)
D_3 (30 SMW)	479	480 (+0.2) (E-M VG)	967 (+102) (PF)	983 (+105)
D_4 (31 SMW)	321	321 (0.0) (EVG)	729 (+127) (EPF)	737 (+130)

FL: Flowering, FL-IN: Flower initiation, MVG: Mid-Vegetative stage, EVG-Early vegetative stage, L-VG: Late vegetative stage, PF-Pod formation stage, EPF: Early pod formation stage, SF: Seed formation, SD: Seed development, LSD: Late seed development stage.

South-west monsoon season during 2015 was a peculiar one with timely onset followed by early season, mid season as well as terminal dry spells in kharif crops. This caused varying degree of adverse effect, depending upon the sowing time and duration of crops. Crop growth stages of Soybean were greatly affected by midseason dry spell during second half of August and terminal dry spell after early cessation of rains from September 19th, 2015. The rainless periods particularly coincided with pod/seed development phase that adversely affected the pod/seed development and final yield performance of the crop, more drastically in late sown crops. This situation has been simulated in DSSAT (CROPGRO Soybean) incorporating simple modifications in the form of application of one or two protective irrigations (50 mm) at different stages of the crop. With this kind of simulation, it was understood that the yield reduction that would have occurred due to the deficit rainfall at a critical stage of the crop was compensated with a single irrigation applied at flowering (27th August) under all the dates of sowing (Table.3). With the application of 2 protective irrigations of the amount 50mm, simulated yield is 1 to 2 times higher than the observed yield under all the four sowing dates.

Jabalpur

Soybean

DSSAT-CROPGRO simulation model for Soybean crop was used for calibrating the cultivar, JS 97-52. A six-year time series data on crop phenological stages, weather, soil, and crop management from 2007 to 2015 was used for generating the genetic coefficients of this cultivar. A total of 16 coefficients were developed, and validated for the accuracy of the model. The results are presented as under:

Calibration of different phenological stages, grain and biomass yield of Soybean crop

The comparison of simulated versus observed values of days to anthesis, days to maturity, seed yield and total biomass yields are presented in the Fig. 5.1. The comparison of observed and simulated days to anthesis (flowering) showed more error in simulating days to anthesis with R^2=0.63; RMSE=16.6 and D-value=0.32. Probably, this phenological stage is indeterminate in nature.

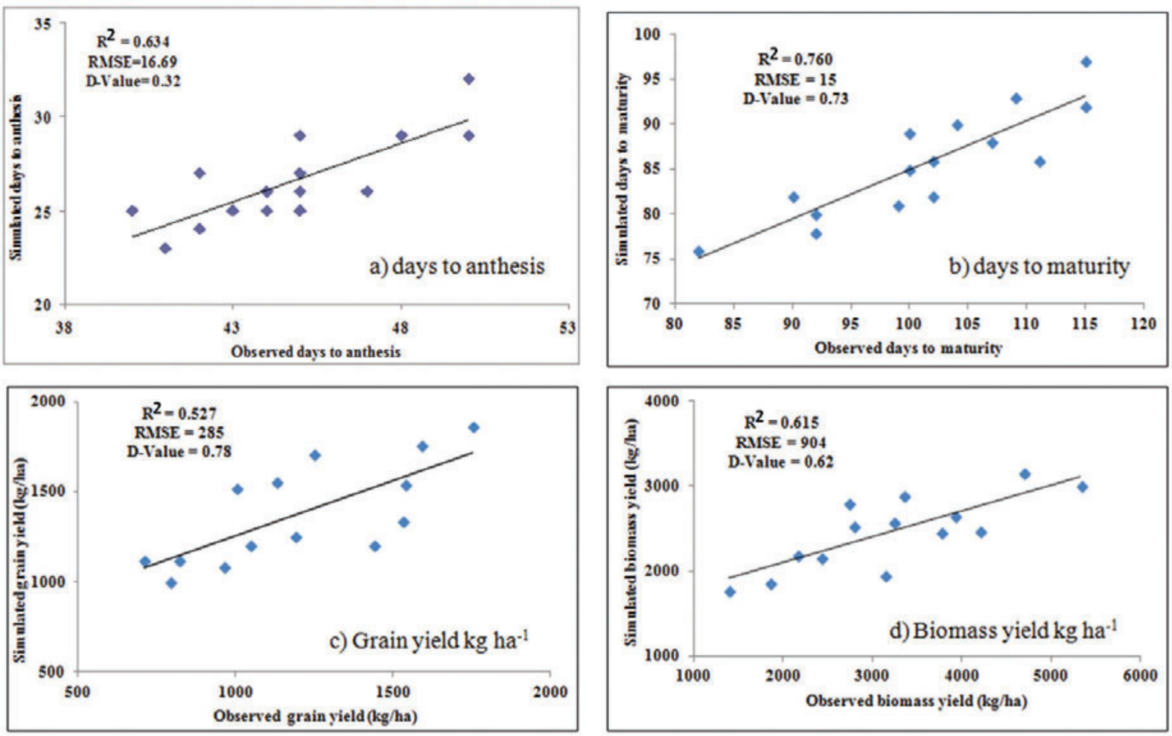


Fig.5.1: Model simulated versus observed values of different crop parameters of soybean at Jabalpur

Similarly, comparison between simulated and observed days to maturity showed a close fit (R^2=0.76) with less error (RMSE=15 and D-value=0.73) indicating a good agreement between observed and simulated days to maturity. Comparison between observed and simulated seed yield showed a poor fit (R^2=0.52) with an error of 285 kg/ha and D-value=0.78. Similarly, total biomass yield showed a good fit of D-value=0.62 making the variability in yields attributed to occurrence of more dry spells, weed infestation and insect-pest attack, especially yellow vein mosaic. This model can further be used for climate change studies, which requires more refinement.

Jorhat

Rice

The CERES-Rice model for cv. Mahsuri which was grown under three dates of transplantation was calibrated (2009-11) and validated (2012-13) for Jorhat conditions and results are presented in Table 5.3. The model was calibrated with the observed phenology and yield. The maturity days require further fine tuning, as the RMSE is very high (19.1 days). During model validation, percent difference between observed and simulated grain yields were -9.0,-8.9 and 9.0%, for dates of transplanting *viz.* D_1 (3rd week of May), D_2 (2nd week of June) and D_3 (1st week of July), respectively. Similarly, in case of days for anthesis also close agreement between observed and predicted values. However, increase of days to maturity, the agreement between observed and simulated is poor at all treatment dates except D_2 i.e. Second week of June.

Table.5.3: Calibration (2009-11) and validation (2012-13) of model results for rice cv. Mahsuri at Jorhat

Variable	Observed	Simulated	RMSE	D-stat
Calibration (2009-11)				
Anthesis day	122	123	3.3	0.92
Grain yield (kg ha^{-1})	3128	3291	1651.9	0.50
Maturity day	164	150	19.1	0.51
Validation (2012-13)				
D_1 (3rd week of May)*				
Anthesis day	125	121		
Grain yield (kg ha^{-1})	2569	2337	(-9.0%)	
Maturity day	152	165		
D_2 (2nd week of June)				
Anthesis day	117	119		
Grain yield (kg ha^{-1})	4553	4145	(-8.9%)	
Maturity day	161	158		
D_3 (1st week of July)				
Anthesis day	103	107		
Grain yield (kg ha^{-1})	3134	3417	(9.0%)	
Maturity day	135	141		

**D_1 (3rd week of May), D_2 (2nd week of June) and D_3 (1st week of July) are the dates of transplanting*

Simulation of Rice yield variability under future Representative Concentration Pathways (RCP) projections

In the calibrated DSSAT rice model for cv. Mahsuri, various RCP scenarios were incorporated as inputs for assessing the climate change impact on rice. The observed mean grain yields during 2009-2013 for three dates of transplantation viz. 2600 (D_1), 4594 (D_2) and 3443 kg/ha (D_3) are considered as baseline yields for comparison, (Table 5.4). The results showed that rice yields are likely to be reduced in all the scenarios, except RCP 8.5, in which the third date transplanted rice is likely to yield more (4.3%). It seems that under the RCP 8.5 scenario,the percentage reduction in yield over baseline period is lesser compared to other scenarios in late sowing conditions. However, for early sowing percentage reduction is likely to be lower in RCP2.6 than the other scenarios. This study requires further insight into the scenario evaluation along with crop calendar of rice crop

Table 5.4: Impact of climate change on the rice yields of cv. Mahsuri at Jorhat under different RCP scenarios and dates of transplantation over baseline conditions (2009-2013) at Jorhat

Periods	Observed grain yield (kg ha^{-1}) (2009-2013)	% Change in grain yield over 2009-2013				
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	Mean
2020 D_1*	2600	-14.4	-14.8	-27.5	-27.5	-21.0
2050 D_1		-14.5	-34.3	-17.1	-35.3	-25.0
2080 D_1		-9.3	-33.8	-27.0	-23.7	-23.0
Mean		-12.7	-27.6	-23.9	-28.8	-23.3
2020 D_2	4594	-27.6	-29.5	-36.7	-36.7	-33.0
2050 D_2		-43.9	-43.5	-44.1	-44.8	-44.0
2080 D_2		-31.1	-38.9	-35.9	-48.8	-39.0
Mean		-34.2	-37.3	-38.9	-43.4	-38.5
2020 D_3	3443	-21.1	-26.8	-14.0	-14.0	-19.0
2050 D_3		-56.6	-58.9	-64.0	-61.9	-60.0
2080 D_3		-14.9	-5.5	-12.2	4.3	-7.0
Mean		-30.9	-30.4	-30.1	-23.9	-28.8

D_1 (3rd week of May), D_2 (2nd week of June) and D_3 (1st week of July) are the dates of transplanting

Rabi

Ludhiana

Wheat

Pre-harvesting forecast of wheat yield using DSSAT wheat model

Using the calibrated and validated DSSAT wheat model, pre-harvesting wheat yield was forecasted during the crop year 2015-16. The actual weather data for Ludhiana station from mid October till different time period (as specified in columns) upto 21st March 2016 andtillering, remainingperiod normal with weather upto maturity was used for this study. The wheat yields as well as crop growth duration during different sowing periods was compared with those predicted using the normal weather for Ludhiana station (Table 5.5). The model was run with an assumption that the crop remained free from strong winds, hailstorm, water, nutrient and biotic stress.

The simulated yield deviation (%) using actual weather upto different time periods under six sowing weeks starting from 4th week of October to 1st week of December showed that the percent deviation of simulated yields using actual weather upto 22nd February 2016 was found to be lowest.

Table. 5.5: Sowing week based pre-harvest yield forecast of wheat crop at Ludhiana

Sowing periods	Deviation in grain yield (%) from a model simulated normal yield of 4995 Kg/ha					
	Upto 9 Feb 2016	Upto 22 Feb 2016	Upto 29 Feb 2016	Upto 7 March 2016	Upto 13 March 2016	Upto 21 March 2016
4th week Oct	-7.3	-4.8	-6.9	-6.6	-6.2	-6.0
1st week Nov	-10.7	-8.5	-10.2	-10.0	-9.2	-9.0
2nd week Nov	-12.2	-10.1	-11.0	-11.0	-10.9	-10.8
3rd week Nov	-12.0	-10.5	-11.8	-11.8	-11.8	-11.5
4th week Nov	-11.2	-11.3	-12.2	-12.8	-13.0	-13.0
1st week Dec	-10.7	-11.7	-12.4	-13.5	-13.7	-13.8
Average / Range	-10.6	-9.5	-10.7	-10.9	-10.8	-10.6

Hisar

Mustard

Experimental data of three mustard cultivars (RH30, Laxmi and RH0749) and weather data were compiled and incorporated in InfoCrop and WOFOST models with an objective to work out the genetic coefficients for mustard crop. Growing degree days (GDD) or Thermal time (TT) accumulated over phenophases viz., germination, vegetative (seedling emergence to anthesis) and grain filling (anthesis to maturity) were presented in Table 5.6. Further, Specific leaf area, rate of growth, rooting depth, grain weight and maximum number of grains were computed and showed in the same table.

Table. 5.6 Genotypic characteristics of mustard for InfoCrop model at Hisar

Genetic constants	Acronym	Unit	RH 30	Laxmi	RH 0749
Thermal time (TT) for germination TT for Seedling emergence to anthesis TT for Anthesis to maturity	TTGERM TTVG TTGFC	°C day °C day °C day	105 850 1020	110 880 1090	120 920 1140
Specific leaf area of variety	SLAVAR	fraction	0.0022	0.0022	0.0024
Potential rate of growth	RGRPOT	fraction	2.02	2.03	2.06
Potential rooting depth growth rate	ZRTPOT	mm d^{-1}	44	45	48
Maximum number of grains hec^{-1}	GNOMAX	Number ha^{-1}	41397000	40383000	44657000
Potential weight of a grain	POTGWT	mg	6.52	5.14	6.07

The InfoCrop model was used for phenology and yield prediction of mustard crop during rabi season 2015-16 and compared with the field data (Table 5.7 & 5.8). The results showed that phenology and yield prediction by the InfoCrop model was within the acceptable limit

Table. 5.7 Observed and predicted values (InfoCrop) of phenology and test weight in three mustard varieties along with error testing at Hisar

Parameters	Days to anthesis (days)			Days to maturity (days)			Test Weight (g)		
	RH 30	Laxmi	RH 0749	RH 30	Laxmi	RH 0749	RH 30	Laxmi	RH 0749
Ob	44.5	48.3	53.2	145.8	148.6	150.4	5.2	5.3	5.7
Sm	46.0	51.0	58.0	148.5	150.9	153.4	5.4	5.8	5.9
SD	1.0	1.9	3.4	1.9	2.2	2.1	0.1	0.3	0.2
PE	3.3	5.6	9.0	1.8	2.1	1.9	5.1	8.9	3.9

Ob: Observed value, Sm: Simulated value, SD: Standard deviation and PE: Percent error

Table 5.8: Date of sowing and variety wise mustard yield simulated by InfoCrop model and its comparison with observed yield at Hisar

Treatments	Observed grain yield (q/ha)	Predicted grain yield (q/ha)	Deviation (%)
D_1	32.0	35.5	10.9
D_2	27.0	29.5	9.3
D_3	22.3	27.7	24.2
V_1 (RH 30)	24.7	26.5	7.3
V_2 (Laxmi)	25.3	25.7	1.6
V_3 (RH0749)	30.3	31.8	5.0

WOFOST model

Further, WOFOST model was calibrated with the experimental crop data and weather data. The genetic coefficient of three mustard cultivars i.e. RH30, Laxmi and RH 0749 were generated using WOFOST model. Further, the model was used to predict phenology, yield and yield attributes of mustard crop during *rabi* season 2015-16 and compared with observed data (Table 5.9 & 5.10). The results on phenology and yield prediction by the WOFOST model showed that the phenological events such as days to anthesis and maturity are under estimated by the model in all genotypes and dates of sowing. However, yield was over predicted in all cultivars and dates of sowings.

Table 5.9: Observed and predicted values (WOFOST model) of phenology and test weight in three mustard varieties along with error testing at Hisar

Parameters	Days to anthesis (days)			Days to maturity (days)			Test Weight (g)		
	RH 30	Laxmi	RH 0749	RH 30	Laxmi	RH 0749	RH 30	Laxmi	RH 0749
Ob	44.5	48.3	53.2	148.6	150.4	151.0	5.2	5.3	5.7
Sm	40.0	44.0	50.6	141.2	140.5	138.0	4.6	4.7	5.2
SD	3.18	3.04	1.84	3.75	5.59	9.19	6.50	0.42	0.35
PE	-10.1	-8.9	-4.9	-3.2	-5.3	-8.6	-15.4	-13.3	-9.8

Ob: Observed value, Sm: Simulated value, SD: Standard deviation and PE: Percent error

Table 5.10: WOFOST model comparison between observed and simulated date of sowing and variety-wise mustard yield at Hisar

Treatments	Grain yield (q/ha)		Deviation (%)	Error (%)
	Ob	Sm		
D_1	32.0	35.5	9.7	10.7
D_2	27.0	28.9	6.4	6.8
D_3	22.3	24.8	9.6	10.6
V_1 (RH 30)	24.7	27.6	10.5	11.7
V_2 (Laxmi)	25.3	28.0	9.2	10.2
V_3 (RH0749)	30.3	33.0	7.8	8.4

6. Weather Effects of Incidence of Pests and Diseases

Identification of the weather related pre-disposing factors that trigger the rapid multiplication of pests or growth of pathogen beyond the economic threshold level is of great importance in pests/disease control. It is also required for devising thumb-rules for pest/disease incidence, which are location specific. Issue of forewarning on the incidence of various key pests and diseases in field / orchard crops has considerable economic importance in view of the cost involved in their management through chemical measures. Thus, development of forewarning models for various pests and diseases with sufficient accuracy and lead time has become vital for pest/disease control. The research efforts made at various centers to develop models for various pests and diseases are presented hereunder:

Mohanpur

Based on the long-term mustard aphid count data collected from the field experiments, weather conditions (Table 6.1) associated with aphid incidences in crops sown over different dates and moisture regimes have been identified.

Table 6.1 Weather conditions (pooled over different dates of sowing) associated with incidence, ETL and peak of aphid population in mustard at Mohanpur

Weather conditions at	Weather parameters (°C)					
	Tmax (°C)	Tmin (°C)	Tmean (°C)	Morning RH (%)	Afternoon RH (%)	RHmean (%)
Initial incidence	25.6-28.6	14.7-18.3	20.1-23.4	78.9-84.2	46.6-62.4	64.0-71.1
ETL onset	25.5-26.0	9.2-10.4	17.3-18.2	87.9-89.7	41.5-42.1	64.7-65.9
Peak incidence	23.6-28.2	9.1-15.0	16.4-21.6	78.3-92.8	31.5-57.9	59.3-75.4
Critical period*	21.7-28.9	7.3-17.8	14.5-23.3	78-98	29-73	53-85

**Period having consistently ≥30 aphids plant^{-1}*

Maximum temperature of 25.6 to 28.6 °C, minimum temperature of 14.7 to 18.3 °C and mean temperature of 20.1 to 23.4 °C were associated with initial incidence of aphid. On the other hand, onset of ETL (≥ 30 aphids plant^{-1}) incidence was governed by Tmax of 25.5 to 26 ^{0}C, Tmin of 9.2 to 10.4 °C and Tmean of 17.3 to 18.2 °C. However, these physical environmental conditions associated with critical period of aphid infestation (period having consistently ≥ 30 aphids plant^{-1}) remained in the range of 21.7-28.9 °C, 7.3-17.8 °C, 14.5-23.3 °C, 78-98 %, 29-73 % and 53-85 % for Tmax, Tmin, Tmean, morning RH, after noon RH and mean RH, respectively.

Ludhiana

Weather based "Thumb Rule Models" for predicting incidence of whitefly in cotton

During *kharif* 2015, there was widespread attack of whitefly in cotton crop in the state. The comparison of whitefly population at Bathinda during 2004 to 2015 (Fig 6.1) shows that the attack of whitefly during *kharif* 2015 was epidemic.

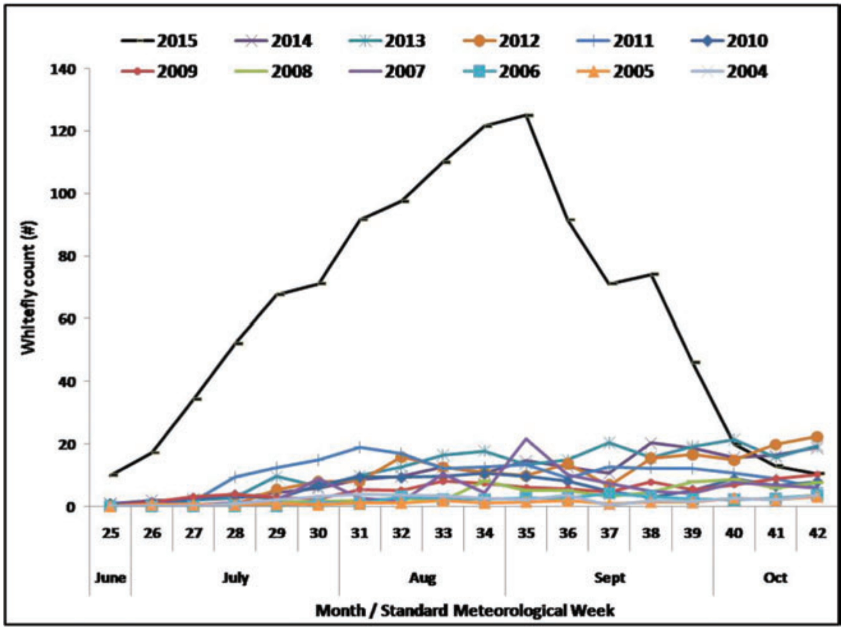


Fig. 6.1 Incidence of cotton white fly at Bathinda during 2004-15

Some of the key factors for severe attack were:

1. Sowing of cotton crop was delayed due to late harvesting of wheat crop. In Punjab about 75% cotton was sown after 15th May and more incidence was reported in late sown crop.
2. The winter of 2014-15 was mild, i.e., minimum temperature was high, relative humidity was more and there was no incidence of frost. These conditions were favourable for the survival of the whitefly during winter season. So early attack (in May June) of whitefly on cotton was noticed.
3. During June month of *kharif* 2015, due to frequent light rainfall the humidity was invariably high (> 65%) and temperature were moderate (<40 °C). These conditions were conducive for buildup of already high whitefly population.
4. During July to September month of *kharif* 2015, no heavy rainfall showers were received which could wash down the already high population of whitefly.
5. Use of sub-standard, spurious and un-recommended mixtures of insecticides was not able to control the whitefly population in cotton crop.

Hence, an analysis of the weekly meteorological parameters and whitefly population trap count at Bathinda over the past 12 years was conducted to create a 'Weather based Thumb Rule' for predicting the incidence of whitefly in cotton. The incidence of whitefly in cotton crop can occur from June to September. The results of the analysis reveal that:

1. Incidence of heavy rainfall (>50mm) can bring down the whitefly population (Fig. 6.2).

2. Favourable ranges of weekly temperature and relative humidity for the buildup of white fly population in cotton are:

- Maximum temperature within the range of 32 to 39 °C[Fig. 6.3 (A)]
- Minimum temperature within the range of 22 to 28 °C[Fig. 6.3 (B)]
- Maximum relative humidity within the range of 73 to 90 % [Fig. 6.4 (A)]
- Minimum relative humidity within the range of 38 to 63 % [Fig. 6.4 (B)]

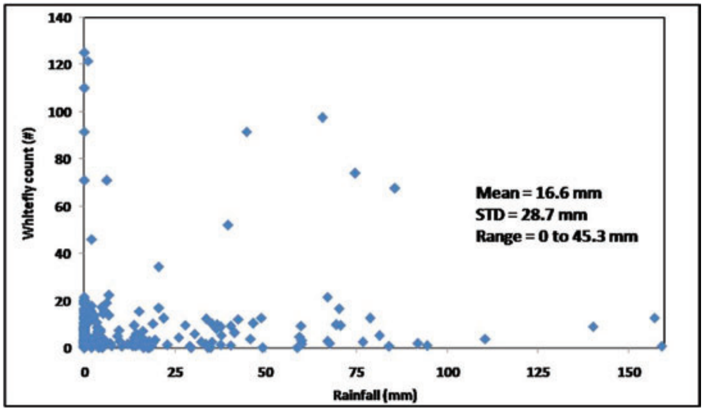


Fig. 6.2 Effect of rainfall on white fly population at Bathinda (Pooled data 2004-2015)

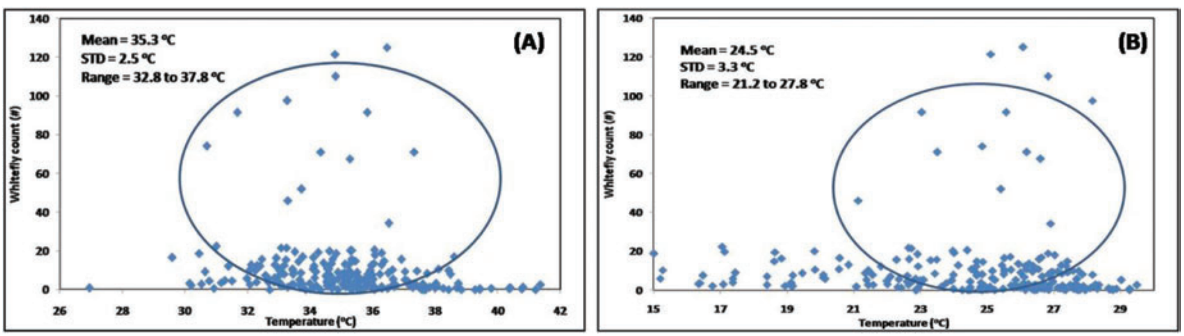


Fig. 6.3 Effect of (A) Maximum temperature and (B) Minimum temperature on white fly population at Bathinda (pooled data 2004-2015)

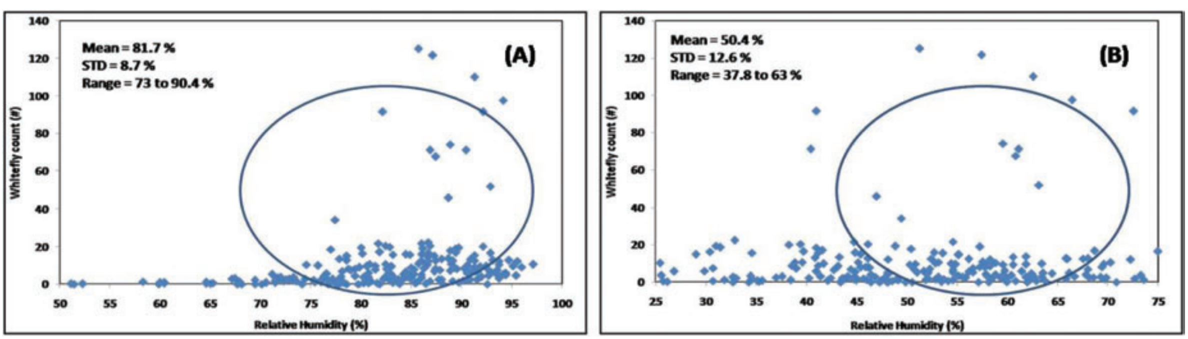


Fig. 6.4 Effect of (A) Maximum relative humidity and (B) Minimum relative humidity on white fly population at Bathinda (pooled data 2004-2015)

Hisar

Effect of weather parameters on cotton white fly infestation

A similar work on the effect of weather parameters on cotton white fly infestation at Hisar center was studied. Data on whitefly population in cotton from 2005 to 2015 were collected and correlated with the weather parameters of SMWs with no rainy day (SMWs with <2.5 mm rainfall) and SMWs with different rainfall amounts (≥ 2.5, ≥ 10, ≥ 15, ≥ 20 and ≥ 25 mm per SMWs) and the results are presented in Table 6.2.

Table 6.2 Correlation of white fly population and weather parameters during non rainy and rainy weeks of different rainfall intensity at Hisar

	Tmax	Tmin	RHm	RHe	WS	BSS	Rain	CUR*
<2.50 mm	0.05	0.11	-0.02	0.05	0.05	0.16	0.16	0.38
>=2.5 mm	0.01	0.06	0.02	-0.02	0.00	-0.06	0.00	0.41
>=10 mm	0.01	0.03	0.11	0.04	-0.04	-0.02	0.00	0.38
>=15 mm	0.01	0.11	0.13	0.05	0.00	-0.03	-0.01	0.35
>=20 mm	0.01	0.12	0.08	0.01	0.04	0.01	0.00	0.35
>25 mm	0.01	0.12	0.08	0.01	0.04	0.01	0.00	0.35

**CUR- Cumulative rainfall, RHm-morning, RHe-evening*

Maximum and minimum temperature, morning and evening RH, wind speed, rainfall and cumulative rainfall (CUR) showed positive correlation with white fly population, whereas bright sun shine hours showed negative correlation. However, cumulative rainfall showed higher positive relation with white fly population, than other weather parameters during rainy days of different intensities and non-rainy days.

Effect of weather parameters on incidence of cotton leaf curl disease

Percent disease incidence (PDI) data on cotton leaf curl disease (2005 to 2015) were correlated with different meteorological parameters. The maximum temperature (-0.58), minimum temperature (-0.48), wind speed (-0.66), evaporation (-0.65), actual vapour pressure (VP) at morning (-0.29) and evening (-0.25), and rainfall (-0.06) showed negative correlation with disease development, whereas morning RH (0.43), evening RH (0.01), sunshine hours (0.19) and cumulative rainfall (0.68) showed positive correlation.

Optimum maximum temperature between 33 to 37°C [Fig. 6.5 (A)], minimum temperature 13 to 21.6°C [Fig. 6.5 (B)]were observed to be congenialfor the disease development. The wind speed showed a highly significant negative correlation with disease development [Fig. 6.5 (C)] which may have favored white fly migration. There was an exponential relationship between disease development and cumulative rainfall [Fig. 6.5 (D)] i.e. the rate of disease development was initially slower till accumulation of 100 mm rainfall but,above 100 mm, disease development increased sharply.

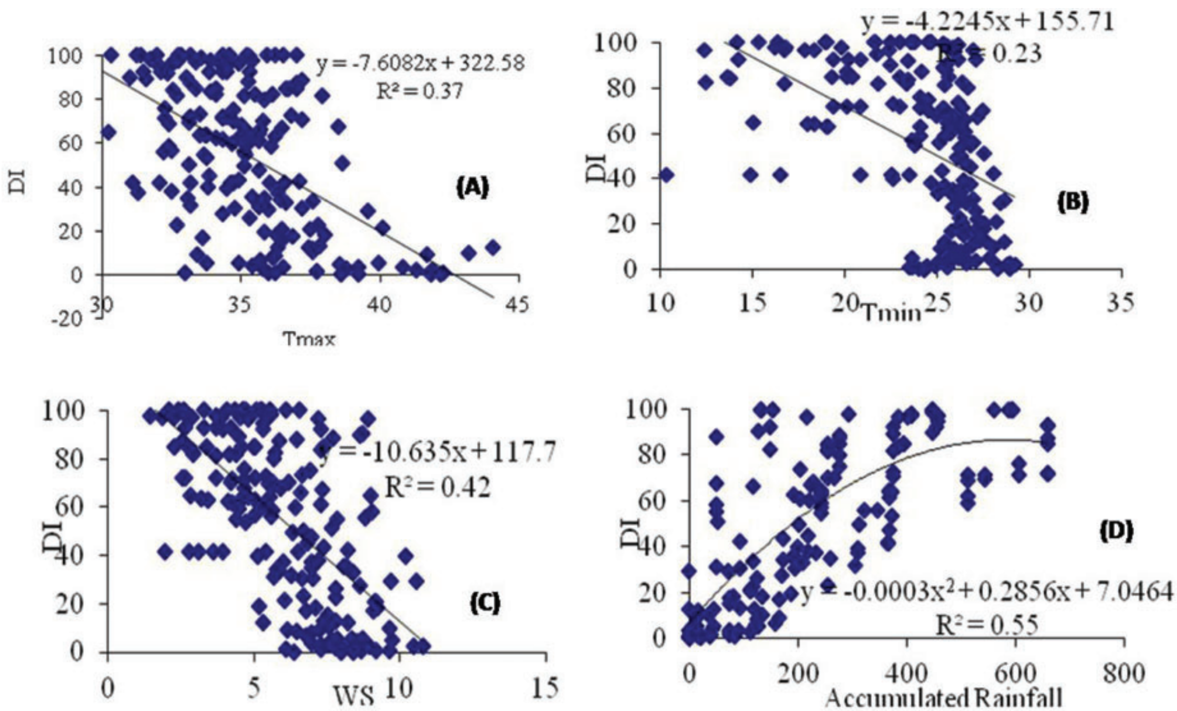


Fig. 6.5 Effect of (A) maximum temperature, (B) minimum temperature, (C) wind speed and (D) accumulated rainfall on percent disease index of cotton leaf curl virus incidence at Hisar (Pooled data of 2005-2015)

Stepwise multiple linear regression method was applied to indentify best suited model using above weather variables.

Multiple regression equation forprediction of cotton leaf curl disease

Y=-113.47 – 1.177*Tmax - 4.80*WS-1.39*PE + 0.07*CUR (R^2=0.65)

This equation could explain upto 65 % variability in cotton leaf curl occurrence in Hisar region.

Jammu

Data on incidence of yellow rust on wheat was collected during rabi 2013-14 and 2014-15 from field experiments in which cultivars HD-2967,PBW-343 and RSP-561 were exposed to three growing environments (sown on 29th Oct, 12th Nov and 26th Nov). The data on disease severity of yellow rust has been correlated with weather parameters and the resultsare presented in Table 6.3.

The results indicated that mean temperature, morning relative humidity and evaporation have significant positive correlation and are most influencing weather factors for the appearance of diseases severity as depicted in Table 6.3. The sunshine and evening relative humidity has not found significant relation with disease severity. As far as varietiesare concerned, PBW-343 is more susceptible to disease followed by RSP-561 and HD-2967.

Table 6.3 Correlation coefficient of yellow rust in wheat with weather parameters under different growing environments

Weather parameter/ Sowing Date	29 Oct	12 Nov	26 Nov
Mean Temp.	0.845**	0.849**	0.813**
Morning RH	0.521**	0.487**	0.400*
Evening RH	0.214	-0.156	-0.091
Sunshine hrs	-0.302	-0.267	-0.208
Evaporation	0.506**	0.401*	0.311

**Significant at 5%; **Significant at 1%*

Jabalpur

A *Helicoverpa armigera* - weather relationship was analyzed during rabi season 2015-16 in different chickpea species (Desi, kabuli, gulabi) grown at different growing environments/ sowing dates (D_1= Nov 21, 2015; D_2=Dec. 05, 2015; D_3= Dec. 20, 2015). Larval population was counted two times (Mon and Friday) per week in the morning hours (8 AM-10 AM) at five different places randomly through a meter scale placed row length wise.The larval infestation started from SMW 2 (8-15 January) of the year 2016 among all the species and more at SMW 7-10.

An association between *Helicoverpa armigera* population/5m row length with the weather parameters in chickpea species was analyzed (Table 6.4). Maximum and minimum temperatures were significantly and positively correlated with larval population. The vapour pressure (morning and evening) showed positive relationship with pest population in all varieties. However, the relationship was significant (significant at 0.05 and 0.01 level of significance) in Desi varieties only.

Table 6.4 Pearson's correlation coefficient between *Helicoverpa almigera* and weather parameters in chickpea species

Chickpea species	Larval population (Numbers/5m row length)							
	Tmax	Tmin	BSS	Rainfall	Wind speed	VapM	VapE	Rainy days
Kabuli	.553*	0.494	0.292	0.207	0.31	0.507	0.474	0.039
Gulabi	0.266	0.436	-0.033	0.329	0.332	0.511	.616*	0.234
Desi	.646**	.556*	0.196	0.228	0.379	.593*	.612*	0.043

***. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed).*

Anantapur

Correlation studies between number of webs per square meter of groundnut leaf miner and weather parameters with 3-day and 7-day lead periods was analyzed at Anantapur. Pooled data during 2012-2015 was used for the analysis and the result is presented in Table 6.5.

Table 6.5 Correlation coefficients between no. of webs per m^2 and weather parameters (Pooled data of 2012 to 2015)

Lead period	Tmax (°C)	Tmin (°C)	RH 1 (%)	RH 2 (%)	SSH (hours)	Rain Fall (mm)	Rain free days	Wind Speed (kmph)
3 day	0.02	-0.11	0.04	-0.17**	-0.19**	0.18**	-0.12**	-0.16
7 day	-0.023	-0.27*	0.14*	-0.19**	-0.24**	0.23**	-0.15*	-0.22**

** Significant at P=0.05, ** Significant at P=0.01*

The analysis revealed that the number of webs per square meter showed significant positive correlation with rain free days and significant negative correlation with minimum temperature, evening relative humidity, sunshine hours and wind speed during the previous 3 days. The results also indicated that the number of webs per square meter showed significant positive correlation with rainfall, morning RH and significant negative correlation with minimum temperature, afternoon RH, Wind speed, sunshine hours and rain free days during the previous 7 days. Correlations of leaf miner with weather parameters at 7 days lead period were found to be better than 3 day lead period.

Anand

Effect of weather parameters on incidence of mustard aphid was studied by Anand center. Field experiment was conducted with GM-2 cultivar exposedto four growing environments [sown on 10th (D_1), 20th (D_2), 30th Oct (D_3) and 10th Nov (D_4) 2015]. The mean aphid index (0-5 Scale) of mustard under different growing environments is presented in Fig. 6.6. Highest peak of aphid intensity was found during seed development phase under all the dates of sowing. Maximum aphid intensity was recorded under crop sown during 20th Oct, followed by 10th Oct, 30th Oct and 10th Nov sown crops. Highest aphid covered plants were observed under 30 Oct

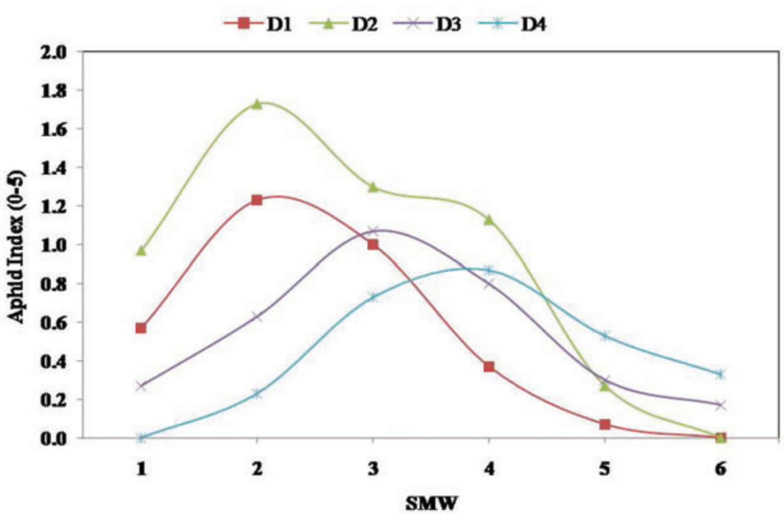


Fig. 6.6 Effect of growing environments on mean aphid index for mustard cultivar GM-2 at Anand during *rabi* 2015-16

and 10th Nov sown crops. Hence, maximum affected plant with lower aphid intensity visually observed under 30th Oct and 10th Nov sowing. Peak of aphid index was 2nd SMW for first and second growing environments, and was shifted to 3rd and 4th SMW for 3rd and 4th growing environments, respectively.

Further, correlation study of aphid intensity and weather parameters was taken up and it indicated that association between aphid intensity and temperature (Tmax, Tmin, Tmean) was significantlynegative,among all the weather parameters (Table 6.6).

Table 6.6 Correlation coefficient between Aphid intensity and weather parameter at Anand

	Tmax	Tmin	Tmean	Trange	RH1	RH2	RHmean
Aphid intensity	-0.713**	-0.777**	-0.758**	-0.23	-0.32	0.29	0.04
**. Correlation is significant at the 0.01 level (2-tailed).							
*. Correlation is significant at the 0.05 level (2-tailed).							

7. Agromet Advisory Services

A delay in onset of monsoon or mid-season drought can hamper the agricultural production in the country, which in turn has many-fold effects on the economy of the country. In addition to this, extreme weather events like hail storm (prevalent at the end of *rabi* season), drought, flood, heavy winds etc. can also cause great damage to field and horticultural crops. The weather aberration warrant the necessity for a scientific weather forecasting system and development of agromet advisories, which are crop and region specific. A timely Agromet advisory can save inputs (seeds, fertilizers, plant protection chemicals etc) as well as the crop (especially at maturity stage). Agromet Advisory Service (AAS) is a part of extension agrometeorology and it is defined as "All agrometeorological and agro-climatological information that can be directly applied to improve and/or protect the livelihood of farmers".

AICRPAM is involved in issuing AAS bulletins twice in a week through its cooperating centers, in vernacular languages. Apart from this, the coordinating unit at CRIDA plays a major role in issuing daily, weekly and monthly bulletins on status of monsoon, progress in *kharif* sowing and AAS for deficit/excess rainfall areas of the country during southwest monsoon. Various AAS products of AICRPAM prepared during southwest monsoon-2015 season is presented in Fig. 7.1.

In India, the preparedness for southwest monsoon starts during second fortnight of April. Around 22nd April every year, South Asian Climate Outlook Forum (SASCOF) issues consensus outlook on the ensuing southwest monsoon. Though the spatial resolution of the forecast is less, it gives a broad idea about the general performance of the monsoon and probable regions of the country where rainfall will be excess, normal and deficit. Project coordinating unit of AICRPAM has overlaid the state map on the SASCOF output map to generate state-specific information. This information on state-wise forecast of rainfall during 2015 southwest monsoon was shared with state government authorities during interface meeting on preparedness for monsoon preparedeness-2015.

Progress of southwest monsoon (2015) was assessed and daily bulletins were prepared, utilizing the data provided by India Meteorological Department (IMD). Weekly bulletins on status of monsoon, progress in kharif sowing and agromet advisories for deficit/excess rainfall areas of the country were prepared with inputs from cooperating centers of AICRPAM.

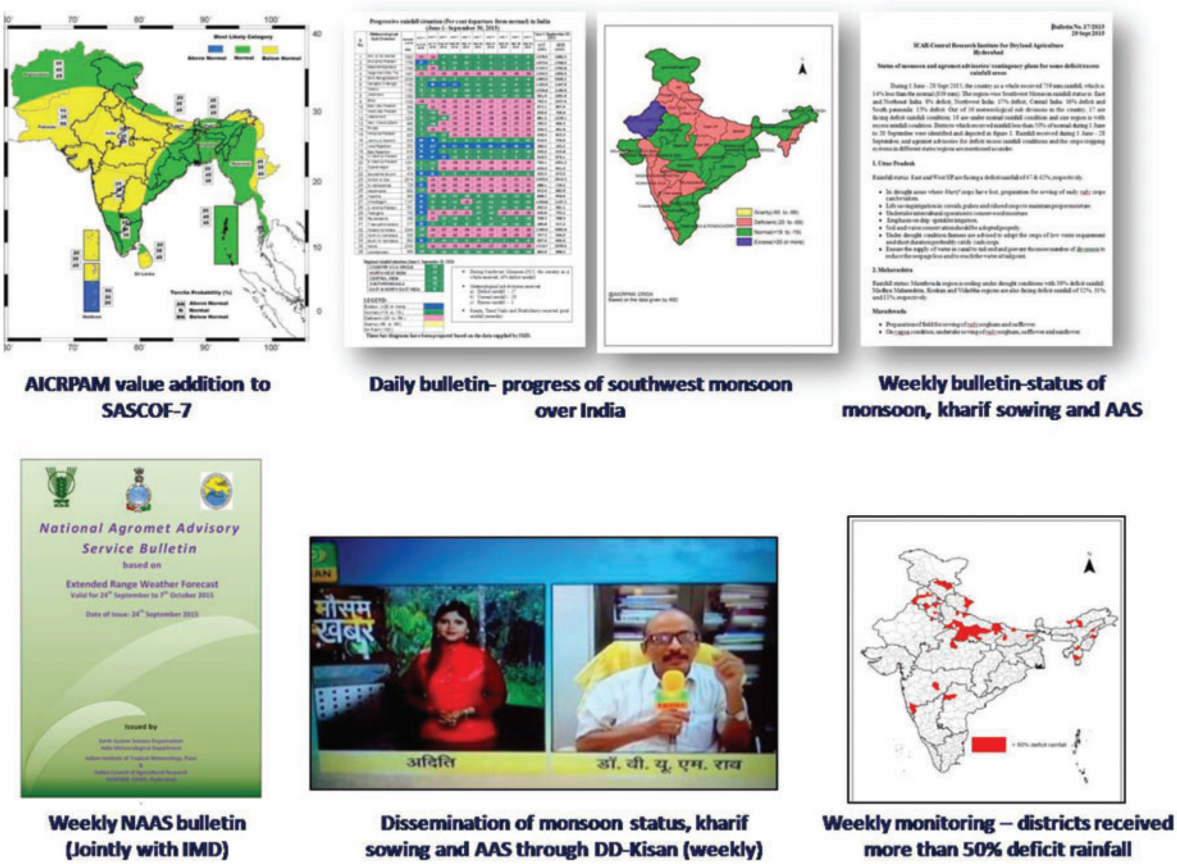


Fig. 7.1 Agromet advisory services of AICRPAM during southwest monsoon-2015

In collaboration with IMD, AICRPAM has issued weekly 'National Agromet Advisory Services' (NAAS) bulletins describing weather conditions prevailed over last week, weather forecast for next two weeks and agromet advisories for major crops for coming week during kharif season. Apart from this, AICRPAM had also provided weekly bulletins on 'Status of monsoon, progress in kharif sowing and agromet advisories for excess/deficit rainfall areas'. Agromet advisories and status monsoon were also disseminated through DD-Kisan channel on weekly basis. Districts which received 50% excess and deficit rainfall were identified on weekly basis for prioritizing areas to implement crop contingency plans.

8. Summary

1. Agroclimatic characterization

- Study of spatial variation in length of growing period (LGP) in Gujarat using climatic data of 17 locations revealed that, LGP ranged from 120-130 days in south Gujarat to 60-80 days in north-western parts of Gujarat state. Valsad, parts of GirSomnath, Surat and Dangs districts have maximum LGP of 120-130 days. Kutch district and part of north Gujarat region showed minimum LGP (< 80 days).
- Trend analysis of the number of spells of 10 days duration with < 2.5 mm rainfall in districts of Vidarbha region, Maharashtra indicated that only Buldana district showed significant (at P=0.05) decreasing trend.
- Study on impact of El Nino on annual, seasonal and monthly rainfall at Anantapur revealed that 32% reduction in annual rainfall was observed during moderate El Niño years, which was significant at P=0.05.
- Demarcation of productivity zones for paddy, sorghum, finger millet and pigeon pea in Karnataka state was undertaken. Areas where scope exists to increase acreage and productivity were identified.
- Climate variability study was undertaken at Ludhiana center by studying trends in weather parameters during *kharif* and *rabi* seasons for different locations of Punjab. The annual maximum temperature increased in North-eastern Punjab, Central Punjab and South-western Punjab. The annual, *kharif* and *rabi* season minimum temperatures have increased in Central Punjab and South-western Punjab.
- Trend analysis of rainy days during southwest monsoon season over West Bengal (1996-2015), indicated a declining trend in major parts of Cooch- Behar, North 24 Parganas, East Midnapur and Bankura districts. Rainy days during SW monsoon showed an increasing trend in some stations of Burdwan, Nadia, Bankura and Hooghly districts.
- Demarcation of productivity zones of wheat in Rajasthan was undertaken. There is a requirement to increase area under wheat and adopt strategies to enhance productivity in Banswara, Pali, Jalore, Dungarpurand Rajsamand districts.
- Length of rainy season in all the 38 districts of Bihar were worked out based on forward and backward accumulation criteria of weekly rainfall at two different probability levels, *viz.* 50 and 75 per cent. Using these criteria, the duration of rainfed cropping period in the districts under various agroclimatic zones of Bihar were identified.

2. Crop weather relationship

Kharif 2015

Rice

- Among three cultivars, Swarna recorded highest RUE (2.7 g/MJ) at Faizabad. On an average, the crop sown on 5 July recorded highest RUE (2.4 g/MJ).

- Relationship between weather parameters and grain yield indicated that both mean maximum temperature and mean temperature during vegetative stage of the crop showed significant positive relation with grain yield (significant at P=0.05) at Kanpur.
- Cultivar *Nayanmani* transplanted on 31 July has the highest RUE (2.76 gm MJ^{-1}) followed by *Swarna,* which recorded RUE value of 2.67 gm MJ^{-1}. *Satabdi* transplanted on 16 June had the lowest RUE value (1.99 gm MJ^{-1}).
- Crop weather relationship studies at Samastipur revealed that mean bright sunshine hours (BSS) during flowering stage showed positive linear relationship with grain yield. The coefficient of determination (R^2) of regression equation explained 64 per cent of total variability in grain yield. Highest grain yield was obtained at a mean BSS of 7 to 8 hours during flowering stage.

Maize

- Higher HUE was recorded under early sown (June 21) crop at all the stages due to higher dry matter production at Jammu. Among the varieties, Kanchan-517 recorded highest HUE followed by Pratap Makka-3 and Kanchan-612, respectively at 70th day after sowing.
- Study on the radiation interception as influenced by growing environments in maize hybrid PMH-1 showed that extinction coefficient increased with the delay in sowing at Ludhiana. The intercepted PAR in the maize canopy reduced with the delay in sowing.

Pearl millet

- The moisture use efficiency (MUE) during total growth period of *kharif* pearl millet at Solapur showed a linear relationship with grain yield. The MUE of 4 to 5 kg ha^{-1} mm^{-1} was found to be optimum for getting higher grain yield.

Pigeonpea

- The pod weight of pigeon pea showed highly significant positive correlation with diurnal temperature range at 150 DAS at Vijayapura.

Soybean

- Study on the effect of growing environments and cultivars on photoperiod and yield at Akola indicated that crop accumulated maximum day length hours for all the phenophases when sown during 28 SMW. The phenology of late sown soybean cultivars was shortened which reduced the total crop duration and finally resulted in lesser yield.

Sunflower

- The moisture use efficiency (MUE) during total growth period of *kharif* sunflower showed a linear relationship with grain yield at Solapur. The MUE of 2.50 to 3.00 kg ha^{-1} mm^{-1} was found to be optimum for getting higher grain yield. The analysis indicated that if RUE increases from 1.1 to 1.2 g MJ^{-1}, it increases the yield from 0.6 to 1.1 t ha^{-1}.

Groundnut

- Large variation in soil moisture depletion was observed in the entire growing environment at Anand. Highest moisture depletion during peg initiation to pod development was observed under crop sown on 29 August, as compared to other two sowings. The pod yield was also lowest (257 kg ha^{-1}) for crop sown on 29 August.
- Growth stage specific crop coefficients were workedout for groundnut at Anantapur. Crop sown on 25 July with a IW/CPE ratio of 1 recorded highest Kc value (2.52), followed by crop sown on 13 August (Kc - 2.24).

Cotton

- Study on the response of cotton genotypes to environmental stress at Akola showed that AKA-7 (*G arboreum*) showed more tolerance to environmental stress compared to others.

Rabi 2015-16

Wheat

- Study on impact of growing environments and cultivars on wheat yield at Hisar indicated that higher radiation use efficiency was found at later stages as compared to initial stages of crop growth.Among different growing environments, the early sown crop recorded more radiation use efficiency at all the stages as compared to delayed sowing. In case of irrigation levels also, radiation use efficiency was found to be low under less irrigated conditions, at all the stages of crop.
- Effect of growing environments and cultivars on yield, yield attributes and heat use efficiency of wheat was studied at Jammu. The heat use efficiency increased with age of the crop up to 105 days after sowing under early and normal sown conditions, whereas under late sown condition, it increased up to 110 days after sowing. The highest HUE was recorded in early sown crop (29 Oct) at all the growth stages. Among the varieties, Raj-3077 recorded highest HUE at all the days of observation.
- Optimum values of weather parameters for achieving higher yield at Ludhiana was worked out using field experimental data of rabi 2009-10 to 2012-13. Maximum temperature of 25 °C and minimum temperature of 9.5 °C from sowing to CRI stage (25-35 days) are optimum for obtaining higher yield. Similarly, maximum temperature range in the range 20.5-23 °C and minimum temperature of 8-10 °C during different post-anthesis stages are optimum temperature ranges for high yield in wheat.
- Study on relationship of mean temperature during vegetative and reproductive phases with grain yield at Palampur revealed that during the year 2013-14 which recorded highest yield, the maximum (16.9, 21 °C) and minimum temperature (4.8, 9.6 °C) were lowest respectively, in both vegetative and reproductive stages among all the five years (rabi 211-12 to 2015-16).
- Highest RUE was recorded in Kanchan, followed by CG 1013 and HD 2967 at Raipur. For the crop sown during 30 Nov, HD-2967 recorded highest RUE. For the crop sown on 15 Dec, the RUE of Kanchan was significantly higher compared to that of CG 1013 and HD 2967.

- The relationship between HUE and RUE with grain yield attempted at Ranchi revealed that both showed positive linear relationship with higher correlation coefficients (0.98 and 0.95, respectively).
- Optimum requirements of maximum and minimum temperatures during different phenological stages of wheat for realization of different yield levels was worked out at Samastipur. It was observed that maximum temperatures above 30.2 and 33.1 °C during 50% flowering to milk and 50% flowering to maturity, respectively reduced grain yield below 2000 kg/ha. During 50% flowering to maturity stage, maximum and minimum temperatures should not be above 29.2 and 14.4 °C respectively, for achieving yield above 4000 kg/ha.

Rabi Maize

- Highest grain yield (5824 kg/ha) and stover yield (10607 kg/ha) were recorded by crop sown during 39 SMW, followed by crop sown during 40 SMW, because of higher rainfall during the crop season at Kovilpatti. Among the hybrids, COH (M) 6 recorded highest grain and stover yield, followed by NK 6240.

Rabi Sorghum

- Relationship of seasonal maximum temperature and minimum temperature with grain yield was studied at Solapur using pooled experimental data during *kharif* 2011-2015. Maximum temperature of around 32 °C and minimum temperature of 18 °C during the growing season of the crop were identified as optimum thermal conditions for obtaining higher yield of rabi sorghum.

Chickpea

- Highest HUE in terms of seed yield was observed (0.45 kg ha^{-1} $°C^{-1}$ day^{-1}) under 41^{st} SMW sowing and with respect to biomass (1.15 kg ha^{-1} $°C^{-1}$ day^{-1}) it was observed under 40 SMW sowing at Akola. Amongst the varieties, heat use efficiency with respect to seed yield (0.47 kg ha^{-1} $°C^{-1}$ day^{-1}) was maximum in JAKI-9218 and biomass production (1.18 kg ha^{-1} $°C^{-1}$ day^{-1}) was highest in Chaffa-816.

Green gram

- Correlation of weather parameters with yield indicated that maximum temperature during germination, vegetative and pod development stages had significant positive correlation (0.67*, 0.62* and 0.61, respectively) and minimum temperature during vegetative, pod initiation and pod development stage had significant positive correlation (0.65*, 0.62*, 0.60* respectively) with grain yield at Kovilpatti.

Mustard

- Highest thermal use efficiency (TUE) at harvest was recorded (0.63 $g/m^2/°days$) in the crop sown on 30 October and the lowest (0.54 $g/m^2/°days$) in the crop sown on 29 November. Maximum thermal use efficiency (0.62 $g/m^2/°days$) from sowing to maturity was recorded in NDR-8501.

- Energy balance studies were conducted at Hisar indicated that around 25 to 85 per cent of net radiation was used as latent heat for evaporation (LE) at different phenophases. The maximum value of LE was recorded at maximum leaf area index stage compared to flowering and pod formation stages, mainly due to increase in accumulation of biomass as well as LAI.

Potato

- Stress free days with more negative canopy-air temperature difference (CATD) values were observed during 44-60 days after sowing in all the three cultivars at Jorhat.
- Highest water use efficiency was achieved under normal date of planting conditions at Mohanpur (11.9 and 11.0 Kg m^{-3} for 2012-13 and 2013-14, respectively). Delayed planting reduced the WUE due to reduction in tuber yield. Among the methods of irrigation, alternate furrow irrigation recorded maximum WUE for both the years.

Horticultural crops

Mango

Climatic water balance studies at Bangalore revealed that out of 1070.5 mm rainfall, 994.4 mm (including previous year's left over moisture) of rain water were used for evapotranspiration by Mango against the requirement of 1345.9 mm.

3. Crop growth modeling

- CROPGRO-Soybean simulation model (DSSAT v 4.5) was evaluated with 3 years experimental data from 2011-2013 at Akola for three different varieties viz., JS-335, JS-9305 and TAMS 98-21 raised under four different environments. Impact of dry spells occurred during southwest monsoon 2015 was studied by simulating the yield generated by irrigation at critical growth stages. With the application of 2 protective irrigations of the amount 50 mm, simulated yield is 1 to 2 times higher than the observed yield under all the four sowing dates.
- DSSAT-CROPGRO simulation model for Soybean crop was used for calibrating the cultivar, JS 97-52 at Jabalpur. Comparison between observed and simulated seed yield showed a poor fit (R^2=0.52) with an error of 285 kg/ha and D-value=0.78. Similarly, total biomass yield showed a good fit of D-value=0.62, making the variability in yields attributed to occurrence of more dry spells, weed infestation and insect-pest attack, especially yellow vein mosaic. This model can further be used for climate change studies, which requires more refinement.
- The CERES-Rice model for cv. Mahsuri which was grown under three dates of transplantation was calibrated (2009-11) and validated (2012-13) for Jorhat conditions.Various RCP scenarios were incorporated as inputs for assessing the climate change impact on rice. The results showed that rice yields are likely to be reduced in all the scenarios, except RCP 8.5, in which the third date transplanted rice is likely to yield more (4.3%).

- Using the calibrated and validated DSSAT wheat model, wheat yield was forecasted during the crop year 2015-16 before harvest at Ludhiana.The simulated yield deviation (%) using actual weather upto different time periods under six sowing weeks starting from 4th week of October to 1st week of December showed that the percent deviation of simulated yields using actual weather upto 22 February 2016 was found to be lowest.
- WOFOST model was calibrated with the experimental crop data and weather data for mustard at Hisar. The genetic coefficients of three mustard cultivars i.e. RH 30, Laxmi and RH 0749 were generated using WOFOST model. Phenological events such as days to anthesis and maturity are under-estimated by the model in all genotypes and dates of sowing. However, yield was over-predicted in all cultivars and dates of sowings.

4. Weather effects on pests and diseases

Cotton

- Analysis of the weekly meteorological parameters and whitefly population trap count at Bathinda over the past 12 years was conducted and favourable range of weather parameters for white fly incidence during June-September was identified (Tmax: 32-39 °C; Tmin: 22-28 °C; RH1: 73-90%; RH2: 38-63%).
- Study on effect of weather parameters on cotton white fly infestation at Hisar center showed that maximum and minimum temperature, morning and evening RH, wind speed, rainfall and cumulative rainfall (CUR) showed positive correlation with white fly population, whereas bright sun shine hours showed negative correlation.
- Optimum weather condition for incidence of cotton leaf curl disease at Hisar was found out. Maximum temperature between 33 to 37 °C, minimum temperature 13 to 21.6 °C was observed to be congenial for the disease development.

Mustard

- Study on weather effects on incidence of mustard aphid at Mohanpur revealed that maximum temperature of 25.6 to 28.6 ^{0}C, minimum temperature of 14.7 to 18.3 ^{0}C and mean temperature of 20.1 to 23.4 ^{0}C were associated with incidence of aphid. On the other hand, onset of ETL (≥ 30 aphids plant^{-1}) incidence was governed by Tmax of 25.5 to 26 ^{0}C, Tmin of 9.2 to 10.4 ^{0}C and Tmean of 17.3 to 18.2 ^{0}C.
- Correlation study of aphid intensity and weather parameters was taken up and it indicated that association between aphid intensity and temperature (Tmax, Tmin, Tmean) was significantly negative, among all the weather parameters

Wheat

- Relationship between disease severity of yellow rust with weather parameters was conducted at Palampur. The results indicated that mean temperature, morning relative humidity and evaporation have significant positive correlation and are most influencing weather factors for the appearance of the diseases. The sunshine and evening relative humidity has not found significant relation with disease severity. As far as varieties are concerned, PBW-343 is more susceptible to disease followed by RSP-561 and HD-2967.

Chickpea

- Relation between *Helicoverpa armigera* population/5m row length with the weather parameters in chickpea species was analyzed at Jabalpur. Maximum and minimum temperatures were significantly and positively correlated with larval population. The vapour pressure (morning and evening) showed positive relationship with pest population in all varieties. However, the relationship was significant (significant at 0.05 and 0.01 P-level) in Desi varieties only.

Groundnut

- Correlation studies between number of webs per square meter of groundnut leaf miner and weather parameters with 3-day and 7-day lead periods was analyzed at Anantapur. Results indicated that correlations of leaf miner with weather parameters at 7 days lead period were found to be better than 3 day lead period.

9. List of Research Publications: 2015-16

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- Singh, A.K., Kumar, N. and Singh, A. (2016). Performance and evaluation of chickpea crop through crop simulation Model DSSAT. In: 4th Uttar Pradesh Agricultural Science Congress on "Strategic Governance and Technological Advancement for Sustainable Agriculture"held at C. S. Azad University of Agriculture and Technology, Kanpur during 2-4 March 2016.
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Radio/TV Shows

- Radio talk on 'Jalvaayu parivartan evam kisaanom ka samaksh chunotiyaan' (Hindi) on 04-02-2016 by Dr. A. K. Singh

Hisar

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Jammu (Chatha)

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sarson (Brassica napus L) cropping system in sub-tropical region under foothills of North –West Himalayas. *Bangl. J. Bot.*, 43 (2): 147-15.

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- TV talk (Star News)on "Monsoon situation in Jammu region" on 30-06-2015 by Sr. Scientist & I/C, Agrometeorology (Dr. Meenakshi Gupta)
- TV talk (Aaj Tak) on "The temperature trend" on 08-12-2015 bySr. Scientist & I/C, Agrometeorology (Dr. Meenakshi Gupta).
- TV Talk (JK Channel) on "The weather situation in Jammu" on 03-02-2016 bySr. Scientist & I/C, Agrometeorology (Dr. Meenakshi Gupta).
- Interview with Sr. Scientist & I/C, Agrometeorology (Dr.Meenakshi Gupta) in ANI channel regarding "Temperature trend and its impact on Agriculture" on 17-03-2016.
- TV talk (ANI) on "Weather situation" on 29-03-2016 by Sr. Scientist & I/C, Agrometeorology (Dr. Meenakshi Gupta).

Jorhat

Papers in Peer Reviewed Journals (International /National)

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Kanpur

Radio/TV Shows

- Radio talk on "Crop management against frost", under Vigyan and Kishan Program on 01.01.2015 by Dr. A. P. Dubey.
- Radio talk on "Kharif planning and weather condition of 2015", under Vigyan and Kishan Program on 01.06.2015 by Dr. A. P. Dubey.

- Dr. A. P. Dubey was delivered weather based agro advisories weekly or by weekly in, Knews, ABC, News nation, India voice,ETV and News state channels.

Kovilpatti

Papers in Peer Reviewed Journals (International /National)

- Arunkumar, N., Solaimalai,A., Jawahar,D., Veeraputhiran, R. and Rao, V.U.M. (2015). Economic use of agro meteorological advisory bulletins chilli in Southern Agroclimatic Zone of Tamilnadu. *Int. J. Agric. Sci.,* 7(14): 879 - 882.
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Ludhiana

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- Harleen Kaur. and PrabhjyotKaur. (2015). Changes in the incidence of extremes of temperature events in Punjab – A case study. In: Proceedings of the National Symposium on "Weather and Climate extremes" held at IMD, Chandigarh during 15-18, February 2015.

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Mohanpur

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Raipur

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- Chaudhary,J.L., Neha Sinha., Patel,S.R., Sanjay Bhelawe. and Manikandan,N. (2015). Analysis of rainfall for rainfed rice production in Chhattisgarh state. *J. Agromet.*, 17(1): 133-135.
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Ranchi

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Samastipur

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- Akashe, V.B., Shinde, S.K., Jadhav, J.D., Bavadekar, V.R. and Amrutsagar, V.M. (2016). Validated forewarning model for safflower aphid (*Uroleucon compositae* T.) in the scarcity zone of Maharashtra. *Contemp. Res. India.*, 1: 49-59.
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- Kanade, S.G., Shaikh, A.A. and Jadhav, J.D. (2015). Effect of sowing dates in groundnut (*Arachis hypogeal* L.) on growth, yield attributing characters and yield. *Adv. Res. J. CropIm.*, 6(1): 05-11.
- Kanade, S.G., Shaikh, A.A. and Jadhav, J.D. (2015). Sowing environments effect on rust. *Int. J. Plant Prot.*, 8(1): 174-181.
- Pardhe, D. D., Thorve, S. B., Jadhav, J. D., Shinde, V. A., Sanglikar, R. V. and Amrutsagar, V. M. (2016).Use watershed – a boost under climate change situation. *Contemp. Res. India.*, 1: 77-80.
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Popular Articles/Leaflets

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Udaipur

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Staff position at cooperating centers during 2015

Centre	Positions Sanctioned and Filled (F) / Vacant (V)					
	Agrometeorologist	Junior Agronomist	Senior Technical Assistant	Meteorological Observer	Field Assistant	Junior Clerk
Akola	F	–	–	F	F	–
Anand	F	F	V	F	F	F
Anantapur	F	F	F	F	F	F
Bangalore	F	V	F	F	F	F
Bhubaneshwar	F	–	–	V	F	–
Bijapur	F	–	–	F	F	–
Chatha/Jammu	F	–	–	F	F	–
Dapoli	F	–	–	F	F	–
Faizabad	V	F	F	F	F	F
Hisar	V	F	V	F	F	V
Jabalpur	V	F	F	V	V	V
Jorhat	F	–	–	F	F	–
Kanpur	F	–	–	F	F	–
Kovilpatti	F	F	F	F	F	F
Ludhiana	F	F	F	F	F	F
Mohanpur	F	F	F	F	F	F
Palampur	F	–	–	V	V	–
Parbhani	F	–	–	F	V	–
Raipur	F	–	–	F	V	–
Ranchi	F	F	F	F	F	F
Ranichauri	V	V	V	V	V	V
Samastipur	F	–	–	V	F	–
Solapur	F	V	F	F	V	F
Thrissur	F	–	–	V	F	–
Udaipur	F	–	–	V	V	–
Total posts sanctioned	25	12	12	25	25	12
Total posts filled	21	7	9	18	18	9

All India Coordinated Research Project on Agrometeorology

Centre-wise and Head-wise RE allocation (Plan) for the year 2015-16 (in lakhs)

S. No	CENTRE	PAY & ALLOW.	TA	RC	IPR/ HRD	NRC Equipment	NEH	* TSP (100%)			TOTAL TSP	TOTAL ICAR SHARE (75%)
								Contingency/ works	Equipment	IT		
1	Akola	18.00	0.30	0.75	-	3.50	-	-	-	-	-	22.55
2	Anand	22.11	0.40	0.80	-		-	10.00	6.00	0.50	16.50	39.81
3	Anantapur	22.00	0.40	0.85	-	4.00	-	-	-	-	-	27.25
4	Bangalore	25.00	0.40	1.00	-		-	-	-	-	-	26.40
5	Bhubaneswar	20.00	0.20	0.80	-		-	23.00	10.00	1.00	34.00	55.00
6	Bijapur	26.00	0.45	0.75	-		-	-	-	-	-	27.20
7	Chatha	17.00	0.25	0.90	-		-	-	-	-	-	18.15
8	Dapoli	8.62	0.10	0.90	-		-	-	-	-	-	9.62
9	Faizabad	33.00	0.35	0.60	-		-	-	-	-	-	33.95
10	Hisar	27.00	0.65	0.90	-		-	-	-	-	-	28.55
11	Jabalpur	25.00	0.25	0.65	-		-	12.00	6.00	0.50	18.50	44.40
12	Jorhat	10.00	0.25	0.75	-		10.00	23.00	6.00	0.50	29.50	50.50
13	Kanpur	24.00	0.30	0.55	-		-	-	-	-	-	24.85
14	Kovilpatti	32.09	0.35	0.80	-		-	-	-	-	-	33.24
15	Ludhiana	42.00	0.20	0.45	-		-	-	-	-	-	42.65
16	Mohanpur	29.00	0.25	1.20	3.00		-	-	-	-	-	33.45
17	Palampur	14.00	0.30	1.00	-		-	-	-	-	-	15.30
18	Parbhani	21.00	0.25	0.90	-		-	-	-	-	-	22.15
19	Raipur	21.50	0.25	0.60	-		-	22.00	8.50	1.00	31.50	53.85
20	Ranchi	39.08	0.15	0.65	-		-	15.81	6.00	0.50	22.31	62.19
21	Ranichauri	1.40	0.15	0.65	-		-	-	-	-	-	2.20
22	Samastipur	11.00	0.30	0.85	-		-	-	-	-	-	12.15
23	Solapur	20.00	0.20	0.50	-		-	-	-	-	-	20.70
24	Thrissur	12.00	0.35	0.65	-	2.50	-	-	-	-	-	15.50
25	Udaipur	19.20	0.40	1.30	-		-	10.00	3.00	0.50	13.50	34.40
26	PC Unit	-	3.00	3.00	3.80		-	-	-	-	-	9.80
TOTAL		540.00	10.45	22.75	6.80	10.00	10.00	115.81	45.50	4.50	165.81	765.81


WELCOME
WORK GROUP MEETING
ON
AICRP ON AGRO-METEOROLOGY
Organized by
ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, BHUBANESWAR - 751003
ICAR


जोखिम मूल्यांकन एवं प्रतिकूल घटनाओं के
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1-21 सितंबर, 2015
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1-21 September, 2015
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