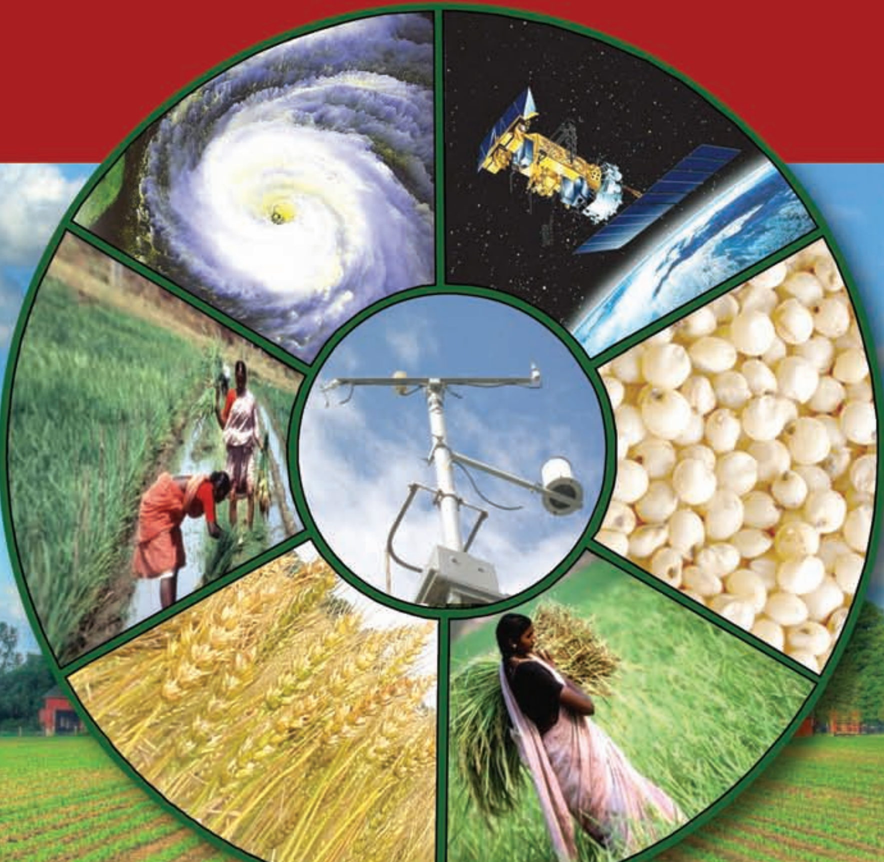
AICRPAM

All India Coordinated Research Project on Agrometeorology

Annual Report - 2010



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Annual Report - 2010

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PREFACE

Weather continues to play a dominant role in agricultural production despite many technological advances made. Increased occurrence of extreme weather events and its impact on agriculture is evident from fall in food grain production during 2002 and 2009 droughts. It is projected that occurrence of extreme weather events are likely to increase further in near future due to climate change.

In this background, the All India Coordinated Research Project on Agrometeorology (AICRPAM) is to play significant role in identifying regions vulnerable to climate change, development of adaptation strategies and dissemination of weather-based agro advisories. Towards achieving this goal, AICRPAM has been carrying out research on impacts of higher temperature and change in rainfall patterns on crops through modeling, preparation of contingency crop plans for different rainfall situations, find out optimum weather requirements at different growth stages of important crops, development of weather insurance products, decision support systems for crop management and forewarning of pests and diseases through its Network Centres located in different agroclimatic zones of the country. Modern tools like remote sensing, GIS and Information Communication Technology (ICT) have also been used in dissemination of research information and agro advisories.

The efforts of the Cooperating Centres of AICRPAM in pursuing the assigned research programs are commendable. However, more needs to be done in areas such as preparation of crop contingency plans at district level, dissemination of agro advisories at the Block level and preparation of mitigation measures to reduce the impact of climate change on agriculture and its allied fields. There is a need for strong linkages between AICRPDA, AICRPAM and NPCC to improve the production and minimize the climate risks in dryland agriculture for sustainable production. The Annual Progress Report of 2010 contains results of research carried out during *Rabi* 2009-10 and *Kharif* 2010 across 25 centres in the country. I take this opportunity to congratulate the efforts made by the Agrometeorologists of all the centres and the Project Coordinator, Dr. VUM Rao and his staff at the Coordinating Unit in compilation of this valuable report.

B. Venkateswarlu

(B. Venkateswarlu)
Director

ACKNOWLEDGEMENT

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The sincere efforts of the Agrometeorologists of all 25 Cooperating Centres in conducting the experiments as per technical program and in brining useful results made it possible to compile a comprehensive report. Help rendered by my colleagues, Drs. B. Bapuji Rao, P. Vijaya Kumar, and AVM Subba Rao in compiling the results of the reports is highly appreciated. Thanks are also due to Shri IR Khandgonda and Smt. Y. Padmini in preparing necessary diagrams and typing the manuscript. Also the continuous support from the Shri A. Mallesh Yadav is acknowledged.

(V.U.M. Rao)
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 evaluating 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 network of 25 Agrometeorological Cooperating Centres are Akola, Anantapur, Anand, Arjia, Bangalore, Bhubaneswar, Bijapur, Dapoli, Faizabad, Hisar, Jabalpur, Jorhat, Kanpur, Kovilpatti, Ludhiana, Mohanpur, Palampur, Parbhani, Raipur, Rakh Dhiansar, Ranchi, Ranichauri, Samastipur, Solapur and Thrissur. The Quinquinnial Review Team has reviewed the research progress of the project in 1992, 1998-99 and in 2006.

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

The Technical Program for the years 2004-06 for different centres of the Project and a common core program decided for all the centres was given below with emphasis on location-specific research needs.

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 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 events and their impacts on agriculture including on livestock, poultry and fish

2) Crop-Weather Relationships (All Centres)

Centre	*Kharif* Crop(s)	*Rabi* Crop(s)
Akola	Soybean	Chickpea
Anand	Groundnut	Wheat
Anantapur	Groundnut	Chickpea
Udaipur	Maize	Wheat
Bangalore	Pigeonpea, Groundnut	Mango
Bijapur	Pigeonpea	Sunflower
Bhubaneswar	Rice	——
Dapoli	Rice	Mango, Cabbage
Faizabad	Pigeonpea	Chickpea
Hisar	—	Mustard, Wheat
Jabalpur	Soybean	Chickpea
Jorhat	Rice	Potato
Kanpur	Maize	Wheat
Kovilpatti	—	Blackgram, Greengram, Maize
Ludhiana	Rice	Mustard, Wheat
Mohanpur	Rice	Mustard, Potato
Palampur	Tea	Wheat
Parbhani	Cotton, Soybean	——
Raipur	Rice	Wheat
Rakh Dhiansar	Maize	Wheat
Ranchi	Rice	Wheat
Ranichauri	Finger millet	Wheat
Samastipur	Rice	Wheat, Winter Maize
Solapur	Pearlmillet	Sorghum, Chickpea
Thrissur	Coconut, Rice	Vegetables

3) Crop Growth Modelling

Compilation of phenology for every crop species

Crop	Lead Centres	Associated Centres
Wheat	Ludhiana	Palampur, Anand, Jabalpur, Rakh Dhiansar, Samastipur, Ranchi, Hisar, Kanpur, Ranichauri
Rice	Raipur	Mohanpur, Samastipur, Dapoli, Faizabad, Thrissur, Bhubaneswar, Jorhat, Ranchi, Kanpur, Jabalpur
Groundnut	Anand	Anantapur, Bangalore

4) Weather Effects on Pests and Diseases

Centre	Crop(s)	Pests/diseases
Anand	Mustard	Aphids, Sawfly, Powdery Mildew, Rust
Anantapur	Groundnut	Leaf miner
Akola	Soybean	Spodoptera
Bangalore	Groundnut	Late leaf spot
	Redgram	Heliothis
Bijapur	Grapes	Powdery mildew, Downy mildew, Anthracnose
	Pomegranate	Bacterial Leaf Blight
Bhubaneswar	Rice	Blight, BPH
Faizabad	Pigeonpea	Pod borer
Jabalpur	Chickpea	Heliothis
Kovilpatti	Cotton	Aphids, Mealy bug
	Blackgram	Powdery mildew
Ludhiana	Rice	Stem borer
	Cotton	Sucking pests
Mohanpur	Mustard	Aphids, Alternaria blight
	Potato	Early blight
Palampur	Rice	Blast
	Mustard	Aphids
Parbhani	Cotton	Mealy bug, Pink boll warm
Ranchi	Rice	BLB, Stem borer, Blast
Ranichauri	Apple	Apple scab
	Amaranthus	Leaf webber

Centre	Crop(s)	Pests/diseases
Solapur	Sunflower	Leaf eating caterpiller
Raipur	Rice	Stem borer, Leaf blast
Kanpur	Rice	Blight, Stem borer
	Wheat	Rust
Thrissur	Vegetables	Leaf spot
Udaipur	Mustard	Aphids
Hisar	Cotton	Leaf curl virus
	Wheat	Karnal bunt
Rakh Dhiansar	Mustard	Aphids

5) Agromet Advisory Services (All Centres)

- Monitoring of crop and weather situation, twice in a week and its updation in 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

WEATHER CONDITIONS DURING THE YEAR 2010

Brief description of rainfall distribution during monsoon and post-monsoon seasons of the year 2010 along with rainfall at 25 centres of AICRPAM is presented hereunder:

Onset of Southwest Monsoon (June – September)

Southwest monsoon set in over Andaman Sea on 17th May, three days prior to its normal date in association with a severe cyclonic storm (LAILA, 16th–21st May 2010) over the Bay of Bengal. The southwest monsoon further advanced over some more parts of Bay of Bengal on 21st May. Finally, monsoon set in over Kerala on 31st May, just one day before its normal onset date (1st June). The advance of monsoon over northeastern parts of the country was earlier than normal date. But monsoon advance over most parts of Bihar and Jharkhand, interior Orissa, Chhattisgarh was delayed by 2-3 weeks than the normal.

A very severe cyclonic Storm (PHET, 31st May–2nd June) formed over the Arabian Sea has delayed further advancement of the monsoon across west coast by about one week. In most parts of central and north India including Madhya Pradesh and Uttar Pradesh, advance of monsoon was delayed by 2-3 weeks and 1-2 weeks, respectively. Severe heat wave conditions prevailed over many parts of north, northwest and central India during this period. The monsoon current advanced over most parts of the country, by 5th July and covered the entire country by 6th July, about 9 days earlier than its normal date of 15th July.

Rainfall distribution during monsoon season

The rainfall during monsoon season (June to September) for the country as a whole and the four broad geographical regions are as follows:

Region	Actual (mm)	Long Period Average (LPA) (mm)	Actual % of LPA	Coefficient of Variation (CV) % of LPA
All-India	912.8	893.2	102	10
Northwest (NW) India	688.2	613.0	112	19
Central India	1027.9	991.5	104	14
South peninsula	853.6	722.9	118	15
Northeast (NE) India	1175.8	1436.2	82	8

The rainfall during monsoon season over the country as a whole was normal during 2010 (102% of LPA). Similarly, the seasonal rainfall was normal over northwest and central India, excess over the Peninsular India and deficient over the northeast India (Table 1.1).

Table 1.1. Sub-divisional rainfall during southwest monsoon – 2010

S. No.	Meteorological Sub Divisions	Actual (mm)	Normal (mm)	% Departure
1	Andaman & Nicobar Islands	1769.5	1693.1	5
2	Arunachal Pradesh	1589.3	1709.5	-7
3	Assam & Meghalaya	1501.3	1951.6	-23
4	Nagaland, Manipur, Mizoram & Tripura	1277.1	1398.7	-9
5	Sub-Himalayan West Bengal	2194	1925.7	14
6	Gangetic West Bengal	788	1140.6	-31
7	Orissa	992.7	1169.3	-15
8	Bihar Plateau (Jharkhand)	644	1084.4	-41
9	Bihar Plains	794	1024.3	-22
10	East Uttar Pradesh	702.1	909.6	-23
11	Plains of West Uttar Pradesh	771.5	771	0
12	Uttaranchal	1690.3	1208.1	40
13	Haryana, Chandigarh & Delhi	565.5	467.3	24
14	Punjab	459	495.7	-7
15	Himachal Pradesh	882.6	773.9	14
16	Jammu & Kashmir	673.9	524.2	29
17	West Rajasthan	443.1	262.5	69
18	East Rajasthan	660	630.3	5
19	West Madhya Pradesh	752.1	903.4	-17
20	East Madhya Pradesh	919.9	1087.5	-15
21	Gujarat (Daman Dadar & Nagar Haveli)	1011.1	910.4	11
22	Saurashtra &Kutch	1005.9	487.1	107
23	Konkan & Goa	3437.4	2799.5	23
24	Madhya Maharashtra	838.5	701.1	20
25	Marathwada	904.1	711.1	27
26	Vidarbha	1216.3	974.9	25
27	Chhattisgarh	1034.6	1203.2	-14
28	Coastal Andhra Pradesh	836.7	575.3	45
29	Telangana	1013.3	766.6	32
30	Rayalaseema	518.9	380.8	38
31	Tamil Nadu & Pondicherry	403.8	313.7	29
32	Coastal Karnataka	3245.3	3174.1	2
33	North interior Karnataka	617.3	491	26
34	South interior Karnataka	742.2	672.2	10
35	Kerala	1933.3	2139.7	-10
36	Lakshadweep	1152.6	985.2	17

Source: IMD

The cumulative seasonal rainfall from 1st June to 30th September 2010 was excess in 14 meteorological subdivisions (43% of the total area of the country) and normal in 17 meteorological subdivisions (42% of the total area of the country). However, five meteorological subdivisions (Eastern U.P, Bihar, Jharkhand, Gangetic West Bengal and Assam & Meghalaya) constituting 15 per cent of the total area of the country received deficient rainfall.

In June, large rainfall deficiency was observed over many subdivisions of central, northern and eastern parts of the country due to delayed advance of monsoon over these regions. However, the rainfall situation over the country improved significantly during July, especially during second half of this month. Normal or excess rainfall was received over most of the subdivisions except a few subdivisions from eastern and northeastern parts of the country where the rainfall was deficient. Rainfall distribution over the country during August was more non-uniform than July, as number of subdivisions with excess and deficient rainfall during August (excess 18 & deficient 9) was more than that during July (excess 13 & deficient 5). During August, most of the subdivisions from northwest and Peninsular India received excess rainfall and most of the subdivisions from eastern part of the country were deficient. However, subdivisions from northeastern part received normal or excess rainfall.

Flood Situation

Flood occurred in some states, *viz.*, Rajasthan, Arunachal Pradesh, Uttar Pradesh, Uttarakhand, Haryana, Punjab and Himachal Pradesh. Flood situations also prevailed over some parts of Gujarat, Maharashtra, Chhattisgarh, Madhya Pradesh, Karnataka and Orissa.

Withdrawal of Monsoon

Like last two years, this year also there was delay in the withdrawal of southwest monsoon due to continued rainfall activity over north India associated with the mid latitude westerly activities. The withdrawal of SW Monsoon from west Rajasthan started only on 25th September (a delay of more than 3 weeks). Subsequently, it withdrew from most parts of the northwestern states and from the northern parts of Gujarat on 28th September. Finally it withdraw from the entire country on 28 October 2010.

Post-Monsoon (October–December) 2010

Post-monsoon (October – December) season rainfall was excess in 18 sub-divisions, normal in 7 sub-divisions, deficit in 10 sub-divisions and scanty/ no rain in one sub-division.

Rainfall at Cooperating Centres

During the year, 3 out of 25 centers of the All India Coordinated Research Project on Agrometeorology, *viz*., Faizabad, Mohanpur and Samastipur received deficient rainfall and rest of the centers received either normal or excess rainfall (Table 1.2).

Table 1.2. Annual Rainfall at AICRPAM centers in the year 2010

S.No.	Center	Actual	Normal	% Departure
1	Akola	1054.6	818.6	29
2	Anand	945.5	853	11
3	Anantapur	887.6	567.8	56
4	Bangalore	1027.6	925.8	11
5	Bhubaneswar	1442.1	1498	-4
6	Bijapur	824.9	594	39
7	Dapoli	4721.1	3557.9	33
8	Faizabad	768.4	1001	-23
9	Hisar	774.9	452	71
10	Jabalpur	1645.4	1209	36
11	Jorhat	2277.7	2148	6
12	Kanpur	998.1	879	14
13	Kovilpatti	877.0	737.3	19
14	Ludhiana	727.0	721.7	1
15	Mohanpur	994.7	1665	-40
16	Palampur	2584.9	1498	73
17	Parbhani	1295.2	963.1	34
18	Ranchi	1401.6	1398.8	0
19	Ranichauri	1848.2	1232	50
20	Raipur	1247.2	1150	8
21	Rakh Dhiansar	1123.0	1106.2	2
22	Samastipur	958.0	1235	-22
23	Solapur	787.3	721.4	9
24	Thrissur	3004.9	2822	6
25	Udaipur	875.3	600.2	46

2. AGROCLIMATIC CHARACTERIZATION

AKOLA

Diurnal Temperature Range (DTR)

As diurnal temperature range (DTR) is an important diagnostic index for the climatic variability, the trends of DTR on seasonal and annual scale were evaluated. The trends in DTR on annual basis and over *kharif* and *rabi* seasons showed significant declining trend of DTR values in both *kharif* and *rabi seasons* and on annual basis (Fig. 2.1).

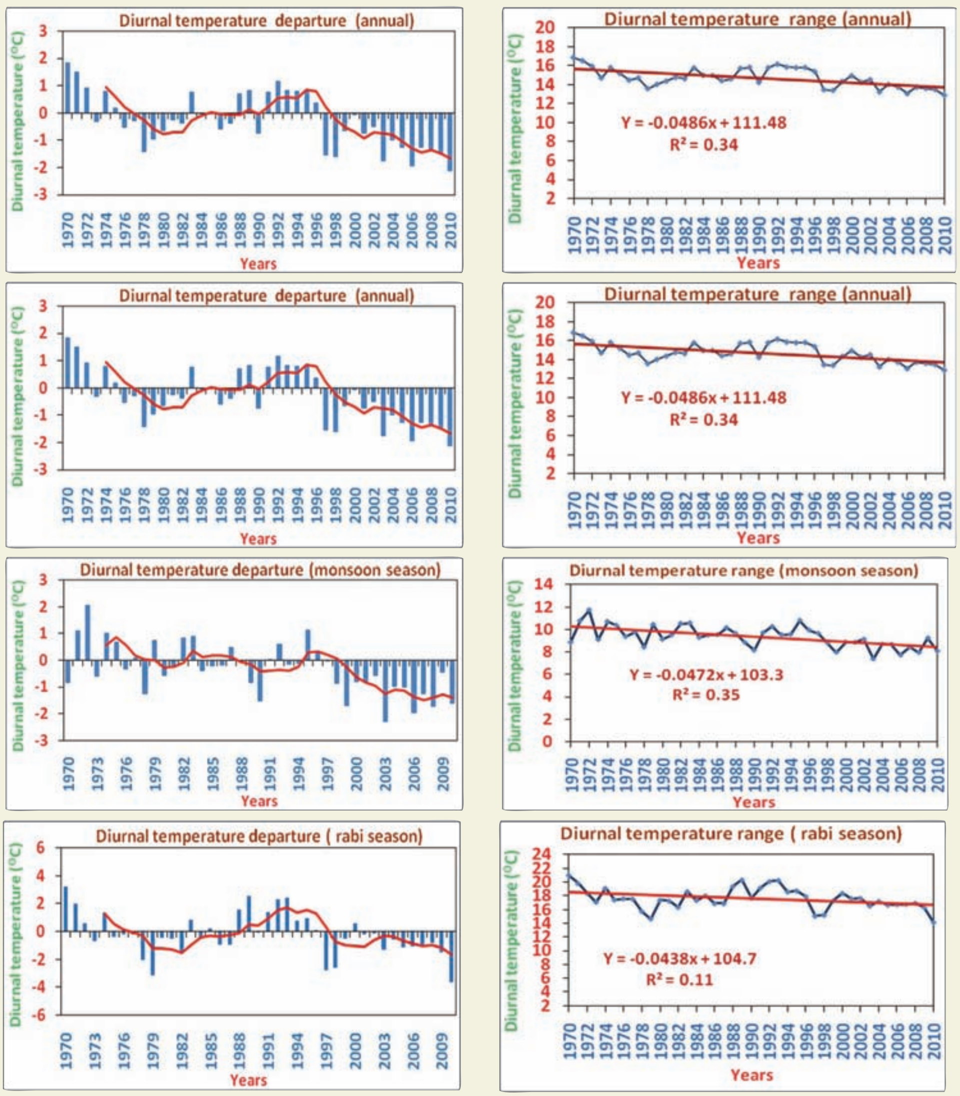


Fig.2.1. Seasonal and annual variability of diurnal temperature range (DTR) at Akola

Reference crop evapotranspiration (ET_o)

Using the daily data of six meteorological parameters, *viz*., maximum temperature, minimum temperature, morning and afternoon relative humidity, duration of bright sunshine and wind speed over the years 1971-2010, reference evapotranspiration ET_o for all the 40 years was estimated with the help of CROPWAT 8.0 for Akola. The time series of annual as well as seasonal ET_o showed significant decreasing trend during all the four seasons and on annual basis (Table 2.1).

Table 2.1. Long-term trends of ET_o over the whole year and seasons

Period	Regression equation	R^2
Annual	Y = -0.035 X + 76.8	0.71
Monsoon	Y = -0.026 X + 58.3	0.35
Post-monsoon	Y = -0.03 X + 67.2	0.69
Winter	Y = -0.34 X + 73.4	0.63
Summer	Y = -0.052 X + 113.0	0.56

Rainfall probability at three locations in Vidarbha

The concept of estimating probabilities of receiving a given amount of rainfall at any location is useful for agricultural planning. Keeping the agricultural planning in view for Vidarbha region, long-term (1971-2010) weekly rainfall data from 22nd to 44th standard meteorological weeks for Akola (western), Yavatmal (central) and Sindewahi (eastern) were analyzed using incomplete Gamma distribution for computing rainfall expected at different probability levels. Rainfall at 75 per cent probability, considered as dependable rainfall and at 50 per cent probability considered as the maximum limit for taking any risk was presented week-wise in Table 2.2. At 75 per cent probability, rainfall of more than 10 mm per week occur continuously for 5 (28-32 SMW), 11 (24-34 SMW) and 12 (25-36 SMW) weeks, respectively at Akola (Western Vidarbha), Yavatmal (Central Vidarbha) and Sindewahi (Eastern Vidarbha). Not only duration of assured rainfall but the amount of rainfall at 75 per cent probability is also less in western region compared to other two regions. Moreover, none of the weeks during the sowing window, i.e., 24-27 SMW at Akola received more than 10 mm at 75 per cent probability, indicating the risk in timely sowing of crops. At 50 per cent probability, rainfall of 10 mm or more occur continuously during the periods 24-40, 24-40 and 23-40 SMW, respectively at Akola, Yavatmal and Sindewahi.

Table 2.2. Weekly rainfall expected at 75 and 50 per cent probability levels at Akola, Yavatmal and Sindewahi

SMW	Precipitation (mm) for the probabilities					
	Akola		Yavatmal		Sindewahi	
	75	50	75	50	75	50
22	0.9	3.6	1.2	4.4	1.3	3.9
23	2.3	9.1	2.6	9.7	2.6	11.2
24	8.0	25.7	10.2	30.6	7.9	23.3
25	8.1	25.7	17.2	40.4	17.2	42.8
26	9.3	27.4	17.6	47.2	27.5	68.5
27	8.3	24.6	17.2	38.2	23.8	57.5
28	11.5	29.3	23.7	49.8	32.4	68.9
29	14.2	36.0	21.9	50.0	39.5	73.4
30	11.4	29.4	17.2	41.5	27.0	56.4
31	10.1	30.5	23.7	57.0	22.3	54.5
32	14.7	39.8	21.0	51.5	35.7	74.0
33	8.9	24.0	15.4	35.8	26.8	60.7
34	6.4	23.0	10.6	31.1	21.4	58.5
35	7.7	24.8	9.2	33.9	16.1	41.2
36	5.3	18.6	8.3	25.8	12.0	34.2
37	2.4	10.9	4.2	14.2	9.6	27.4
38	3.7	13.2	4.5	17.4	3.0	11.4
39	4.2	14.1	4.4	14.5	3.8	15.8
40	2.6	11.3	2.9	12.7	2.8	12.1
41	1.2	5.9	1.5	6.4	0.7	4.2
42	0.9	3.6	1.4	6.0	0.9	6.9
43	0.7	3.6	0.9	3.8	0.9	4.5
44	0.8	2.1	0.9	1.9	0.8	2.5

ANAND

Twenty one years (1989-2009) individual monthly rainfall data of the four monsoon months, i.e., June, July, August and September as well as the monsoon season at four locations, *viz*., Arnej, Godhra, Navagam and Vadodara of Ahmedabad district were analyzed for studying the long-term climate changes. Except rainfall in July at Arnej and in August at Vadodara, no significant trends in any of the months or monsoon season at four locations of Ahmedabad district were observed (Fig.2.2a & b).

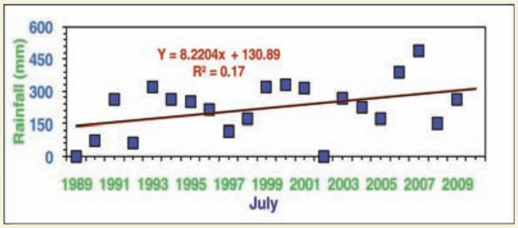


Fig.2.2a. Trends of rainfall in July at Arnej of Ahmedabad district

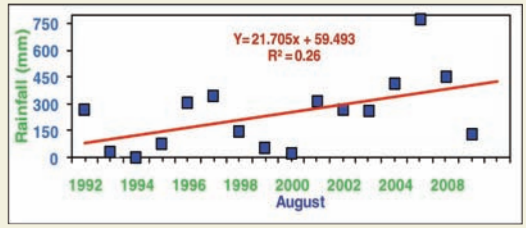


Fig.2.2b. Trends of rainfall in August at Vadodara of Ahmedabad district.

ANANTAPUR

Using long-term (43 years) rainfall data of Anantapur, probabilities of weekly rainfall and dry and wet spells, extreme rainfall years, length of growing period and frequency of high rainfall events were worked out.

Probability of weekly rainfall

The weekly rainfall expected at probability levels of 10, 25, 50, 75 and 90 per cent (Table 2.3) brought out that 10 mm or more weekly rainfall at 50 per cent probability could be expected during 29-30 and 34-42 SMW only.

Table 2.3. Weekly rainfall expected at different probability levels at Anantapur

SMW	Weekly precipitation (mm) for the probabilities					
	90	75	50	25	10	Mean
1	0.8	0.9	1.0	1.2	1.3	0.0
2	0.4	0.7	1.2	1.8	2.6	0.4
3	0.5	0.8	1.2	1.7	2.4	0.3
4	0.5	0.7	0.9	1.3	1.6	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.4	0.1	1.8	2.4	0.1
7	0.0	0.1	0.3	2.5	3.6	0.3
8	0.0	0.1	0.3	2.5	3.6	0.3
9	0.3	0.7	1.3	2.3	3.5	0.7
10	0.1	0.6	2.1	5.2	9.9	2.8
11	0.2	0.7	1.6	3.2	5.4	1.3
12	0.2	0.6	1.5	3.2	5.5	1.3
13	0.4	0.7	1.4	2.4	3.6	0.8
14	0.2	0.6	1.8	3.8	6.6	1.7
15	0.3	0.8	2.0	4.0	6.6	1.9
16	0.3	0.9	2.5	5.6	9.8	3.0
17	0.2	0.9	3.7	10.1	19.9	6.5

SMW	Weekly precipitation (mm) for the probabilities					
	90	75	50	25	10	Mean
18	0.2	1.0	3.9	10.4	20.4	6.7
19	0.3	1.4	4.9	12.6	24.0	8.3
20	0.3	1.5	6.4	17.8	35.5	12.3
21	0.4	2.0	8.1	22.1	43.7	15.5
22	0.5	2.2	6.9	16.3	29.9	10.9
23	0.7	3.2	12.0	31.4	60.7	22.2
24	0.4	2.0	7.5	19.4	37.3	13.3
25	0.4	1.6	5.1	12.2	22.5	7.9
26	0.3	1.4	5.1	13.4	26	8.9
27	0.5	1.8	5.5	12.6	22.8	8.2
28	0.4	2.1	8.9	25	50.1	17.7
29	0.3	2.1	10.3	32	67.7	23.6
30	0.5	2.7	11.1	30.6	61	21.9
31	0.5	2.2	7.4	18	33.5	12.2
32	0.6	2.3	7.4	17.5	32.2	11.8
33	0.5	2.2	7.3	17.7	32.9	12.0
34	0.4	2.7	12.1	35.5	72.9	25.9
35	0.3	2.2	11.6	36.4	77.6	27.1
36	0.7	3.4	13.0	34.6	67.4	24.6
37	1.1	5.2	18.1	45.6	86.4	32.5
38	1.8	7.2	23.5	56.4	104.2	40.2
39	1.5	6.4	21.0	51.2	95.2	36.4
40	1.9	7.1	21.5	49.6	89.4	35.0
41	0.6	3.2	12.3	32.9	64.4	23.4
42	0.7	3.3	12.1	31.7	61.2	22.4
43	0.4	2.3	9.3	25.4	50.2	17.9
44	0.5	2.3	7.8	19.5	36.7	13.3
45	0.2	1.2	5.6	16.4	33.7	11.4
46	0.2	1.1	4.5	12.7	25.6	8.5
47	0.2	0.9	2.6	5.9	10.7	3.3
48	0.2	0.7	2.5	6.2	11.7	3.5
49	0.2	0.8	2.5	6.0	11.2	3.4
50	0.3	0.8	1.9	3.5	5.7	1.6
51	0.4	0.8	1.3	2.1	3.1	0.6
52	0.2	0.7	1.9	4.1	7.2	2.0
Annual	**341.7**	**431.0**	**547.6**	**683.6**	**823.4**	**567.8**

Characteristics and classification of rainfall

Using the criteria followed by IMD for classifying excess (+20% more deviation from normal), normal (± 19% deviation from normal) and deficit (-20 to -59% deviation) and scanty (-60 to -99% deviation) rainfall, years from 1966 to 2008 at Anantapur were classified as any of the four categories (Table 2.4). Similar classification was made for crop season in each year. From this classification, it was identified that annual rainfall is excess, normal, deficit and scanty in 10, 23, 8 and 2 years, respectively. Similarly, rainfall during crop growing period is excess, normal, deficit and scanty in 12, 17, 12 and 2 years, respectively.

Table 2.4: Characteristics and classification of rainfall at ARS, Anantapur (1966- 2008)

Year	Annual Rainfall (mm)	Category of Annual rainfall(mm)	Crop season's rainfall	
			Rainfall (mm)	Category
1966	615.7	Normal	426.3	Normal
1967	565.6	Normal	465.9	Normal
1968	522.2	Normal	372.7	Normal
1969	553.0	Normal	438.3	Normal
1970	592.5	Normal	440.5	Normal
1971	580.6	Normal	455.5	Normal
1972	479.1	Normal	313.5	Deficit
1973	737.5	Excess	684.6	Excess
1974	547.5	Normal	358.5	Normal
1975	628.0	Normal	551.0	Excess
1976	294.1	Deficit	276.1	Deficit
1977	764.3	Excess	473.1	Normal
1978	512.5	Normal	420.8	Normal
1979	619.9	Normal	539.4	Excess
1980	222.9	Scanty	121.2	Scanty
1981	528.2	Normal	476.0	Normal
1982	604.3	Normal	466.2	Normal
1983	665.5	Normal	455.8	Normal
1984	176.3	Scanty	137.8	Scanty
1985	392.0	Deficit	321.4	Deficit
1986	417.6	Deficit	266.0	Deficit
1987	489.0	Normal	459.0	Normal
1988	901.0	Excess	735.0	Excess
1989	806.0	Excess	680.0	Excess
1990	519.0	Normal	355.0	Normal
1991	415.0	Deficit	228.0	Deficit

Year	Annual Rainfall (mm)	Category of Annual rainfall(mm)	Crop season's rainfall	
			Rainfall (mm)	Category
1992	481.0	Normal	397.0	Normal
1993	674.0	Normal	618.0	Excess
1994	376.0	Deficit	207.0	Deficit
1995	742.0	Excess	650.0	Excess
1996	860.6	Excess	576.2	Excess
1997	507.6	Normal	297.6	Deficit
1998	937.2	Excess	765.4	Excess
1999	470.4	Normal	332.6	Deficit
2000	599.8	Normal	353.8	Normal
2001	731.2	Excess	642.4	Excess
2002	389.4	Deficit	278.8	Deficit
2003	256.2	Deficit	228.2	Deficit
2004	495.6	Normal	307.2	Deficit
2005	685.0	Excess	535.6	Excess
2006	452.6	Deficit	194.4	Deficit
2007	989.8	Excess	699.0	Excess
2008	619.0	Normal	462.4	Normal
Average	**567.8**		**429.4**	

Length of growing period (LGP) in three categories of years

Start, end and length of growing season averaged over excess, normal and deficit rainfall years at Anantapur (Table 2.5) showed that during deficit rainfall years, starting week is delayed by 2 weeks compared to excess and normal years and as a result, the duration of crop season was curtailed by two weeks (14 weeks duration) than in excess or normal years (16-17 weeks duration).

Table 2.5: Length of growing period during normal, excess and deficit rainfall years

Category of rainfall during rainy Season	No. of Years	Mean starting Week	Mean ending Week	Mean duration (Weeks)	Mean rainfall during Crop Season (mm)
Normal	17	29 (16 – 22 July)	45 (5-11 Nov)	17	438
Excess	12	29 (16-22 July)	44 (29 Oct - 4 Nov)	16	640
Deficit	14	31 (30 July-5 Aug)	44 (29 Oct - 4 Nov)	14	251

High rainfall events

Decade-wise high rainfall events of 50-75, 75-100 and >100 mm in a day over past four decades (Fig.2.3) showed no increasing or decreasing trend over the progressing decades. However, high rainfall events exhibited cyclic pattern with alternate decreasing and increasing trends in successive decades.

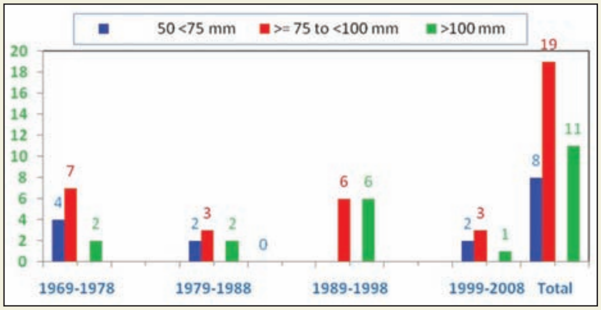


Fig.2.3. Decade-wise high rainfall events of different amounts at ARS, Anantapur

BIJAPUR

Taluk-wise climatological analysis of rainfall data for six districts located in the northern dry zone, northeastern dry zone, northeastern transition zone, northern transition zone and coastal and hilly zone of Karnataka was performed. Daily data of 50 years from 1951 to 2000 were considered for this purpose. Analysis of rainfall duration periods indicated that the standard deviation of starting, end and duration of rainy season was more in drier districts of Bellary (Northern Dry Zone), Gulbarga and Raichur (Northeastern Dry Zone) and hotter district of Bidar (Northern Transition Zone), while in the districts situated in the Northern Transition Zone (Belgaum district) and Coastal Zone (Uttara Kannada district) lower variability was noticed (Table 2.6).

Table 2.6. Commencement and end of rainy season in different districts of Karnataka

Variable	Statistics	District					
		Bellary	Gulbarga	Bidar	Raichur	Belgaum	Uttar Kannada
Starting of rainy season	Mean	24	24	23	27	24	22
	Earliest	22	22	22	25	22	22
	Latest	31	28	26	33	30	25
	Std. Dev.	2.2	1.4	1.1	1.8	1.8	0.8
Ending of rainy season	Mean	45	44	45	45	45	45
	Earliest	40	38	37	40	38	39
	Latest	52	52	52	51	52	52
	Std. Dev.	2.9	3.4	3.8	2.9	3.1	3.0
Duration of rainy season	Mean	21	21	22	18	21	23
	Minimum	12	12	14	11	12	16
	Maximum	29	28	30	25	29	29
	Std. Dev.	3.5	3.6	3.7	3.3	3.6	3.1

HISAR

Weekly water balance

Average weekly water balance was calculated for Hisar station using Thornthwaite's method. The soils are light, sandy and sandy loam in texture with water holding capacity (WHC) of 100 (sandy) to 175 mm/m in sandy loam to loamy soils. The station receives 455.0 mm rainfall annually as against potential evapotranspiration (PET) of 1639.0 mm indicating a water deficit of 1184.0. The actual evapotranspiration (AET) as derived from water balance was 470.2 mm, approximately equaling the mean annual rainfall and near about one third of the potential evapotranspiration.

Growing season duration

A perusal of availability of number of weeks with reasonable amount of rainfall for successful raising of crops at Hisar (Table 2.7) during *kharif* season indicated that average growing period starts in 27th SMW lasting till 41st SMW thus extending over 15 weeks. The duration of crop growing season ranged between 5 (1974) and 23 weeks (1970) and farmers need to adopt contingency measures for success of crops under limited/excess rainfall conditions. There were three instances (1987, 1989 & 2002) when rainfed crops failed completely because of failure of monsoon rains in the region.

Table 2.7. Start, end and duration of growing season at Hisar

Year	Standard Meteorological Week		Duration (Weeks)	Rainfall during season (mm)
	Start	End		
1970	26	48	23	466.3
1971	32	39	8	321.9
1972	20	25	6	226.7
1973	28	37	10	193.5
1974	29	34	5	252.8
1975	28	49	22	408.3
1976	26	44	19	665.1
1977	25	46	22	445.1
1978	28	42	15	539.1
1979	28	36	9	348.3
1980	26	42	17	193.9
1981	29	38	10	351.3
1982	30	47	18	254.6
1983	34	46	13	391.1
1984	28	44	17	330.2
1985	26	45	20	425.4

Year	Standard Meteorological Week		Duration (Weeks)	Rainfall during season (mm)
	Start	End		
1986	26	45	20	299.1
1987		No Growing season		63.5
1988	28	44	16	665.6
1989		No Growing season		156.1
1990	27	48	22	444.0
1991	34	41	8	297.5
1992	26	47	22	359.1
1993	27	44	18	366.3
1994	29	48	20	490.4
1995	30	47	18	482.3
1996	24	45	22	360.0
1997	22	46	24	452.9
1998	27	12	38	414.2
1999	29	35	7	192.8
2000	28	33	6	122.2
2001	22	43	22	538.0
2002		No Growing season		91.7
2003	27	45	19	431.5
2004	33	44	12	189.3
2005	26	42	16	457.7
2006	26	40	15	243.7
2007	24	40	17	323.4
2008	24	44	18	496.1
Mean	**27**	**41**	**15**	**352.6**

JORHAT

Analysis of long-term (1901-2010) rainfall and its deviation from normal during monsoon season at Jorhat (Fig.2.4) brought out that percentage deviation of rainfall from normal is slipping from positive to negative deviation from the early sixties of the 20th Century. From the year 1980 onwards, more number of years with negative anomaly (20) were witnessed than the number of years with positive anomaly (6) at Jorhat.

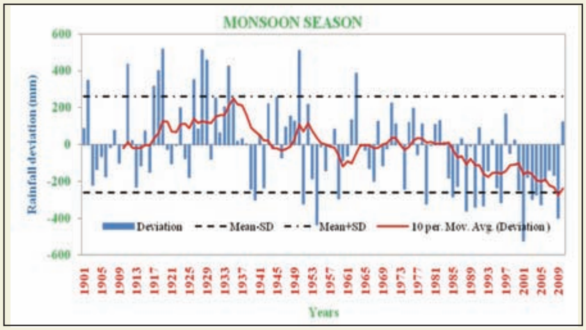


Fig.2.4. Trend in rainfall during monsoon season at Jorhat.

Decadal variation in annual rainfall

Deviations of decadal averages of rainfall from the long-term mean for the last 11 decades starting from 1901 (Fig.2.5) showed that the deviations or anomalies followed cycles of 3 to 4 decades. The positive deviations in rainfall for four decades during 1911-50, remained normal for next three decades (1951-80) later turned negative during the current three decades (1981-2010). The highest negative deviation in rainfall was observed in the current decade of 2001-10.

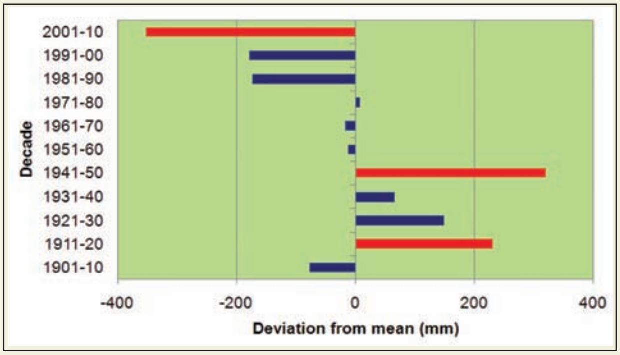


Fig.2.5. Decadal variation in annual rainfall at Jorhat

Trends in temperature

Analysis of past 40 years data on maximum, minimum and average temperatures besides the annual temperature range (Fig.2.6) revealed that minimum temperature is increasing at an higher rate (0.013°C/year) than maximum temperature (0.009°C/year) and as a result showing decreasing trend in annual temperature range.

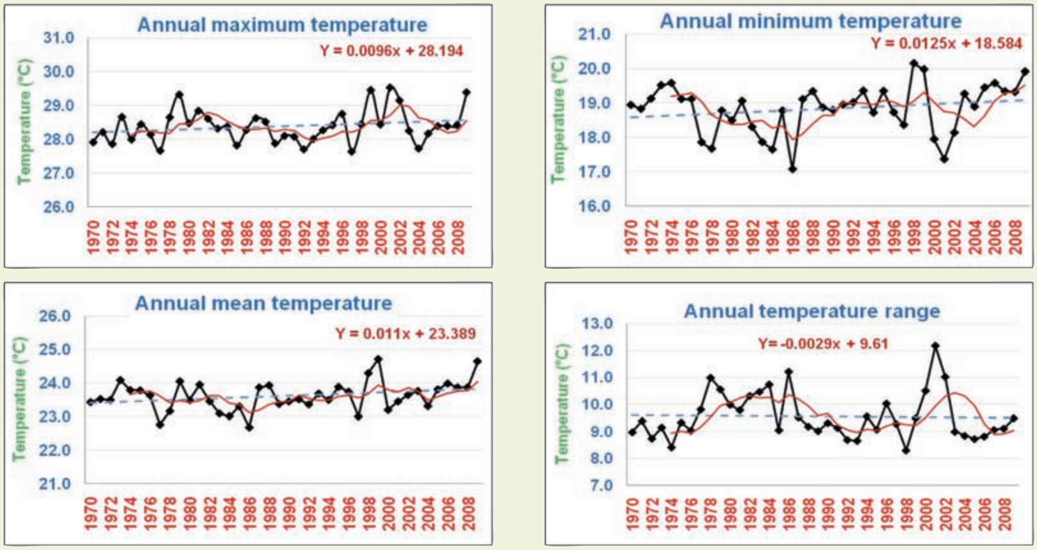


Fig. 2.6. Variations in annual temperature and temperature range at Jorhat

KANPUR

Decadal change in rainfall

Decadal or 10 years average rainfall during the period 1971-2010 (Fig.2.7) showed decrease in rainfall from decade to decade during last four decades. The decadal average rainfall decreased by 101 mm from 920 mm during 1971-80 to 819 mm during 2001-2010.

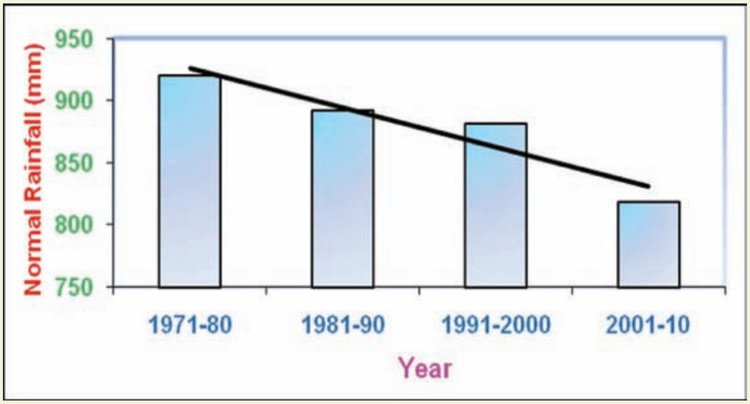


Fig.2.7. Variation in decadal rainfall at Kanpur

Trends in monthly maximum and minimum temperature

Depiction of trends (slope of regression equations) in both maximum and minimum temperature in all the 12 calendar months (Fig.2.8 & 2.9) brought out that maximum temperature in February and August months only are having significant increasing trends of 0.05°C/year or more. None of the months are showing significant increasing trend in minimum temperature of 0.05°C/year or more. Inter-annual fluctuations in maximum temperature were observed to be more in May, September and November months. The inter-annual fluctuations in minimum temperature were more in January, August and September months.

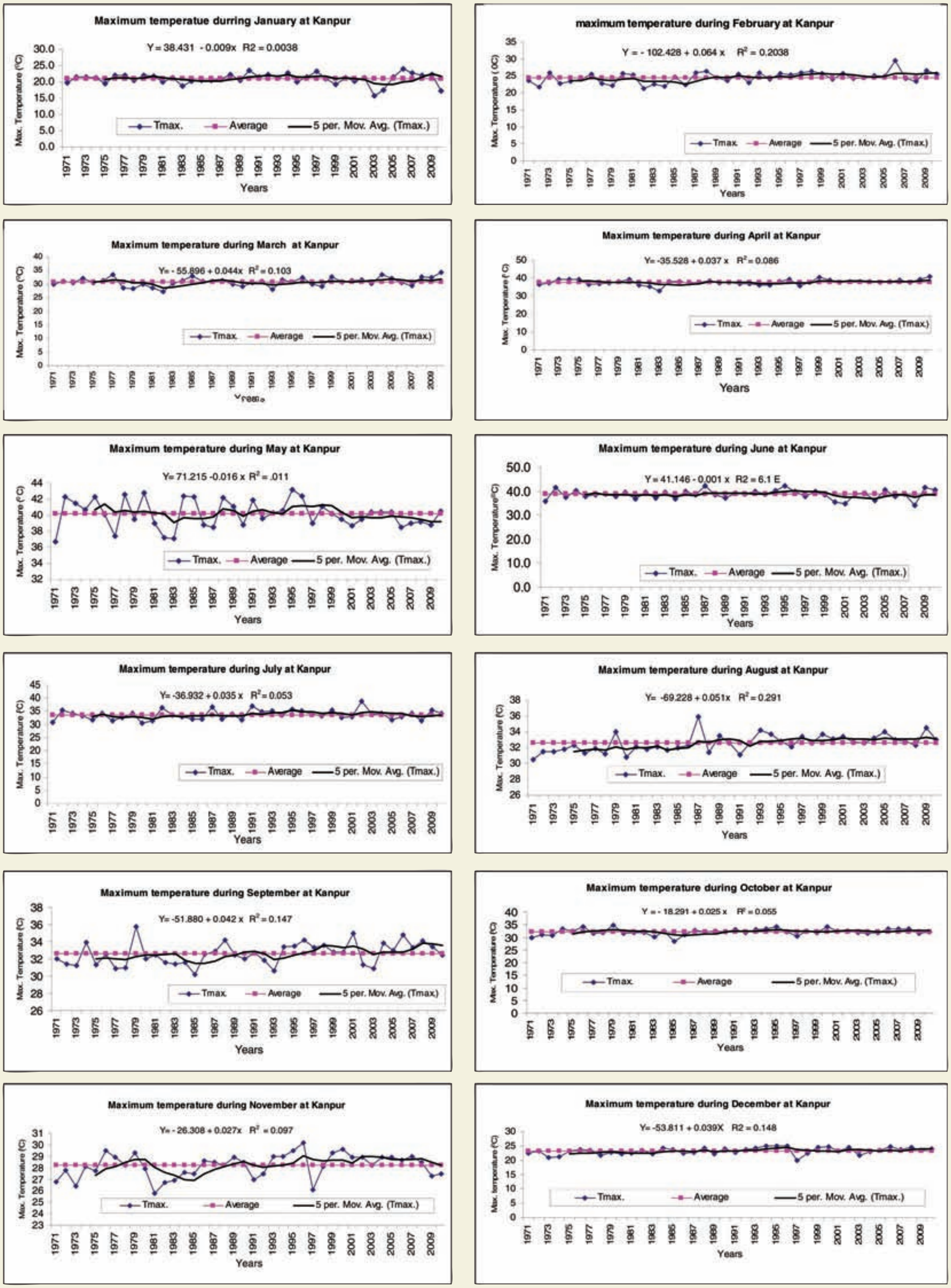


Fig.2.8. Monthly maximum temperature trend at Kanpur (1971-2010)

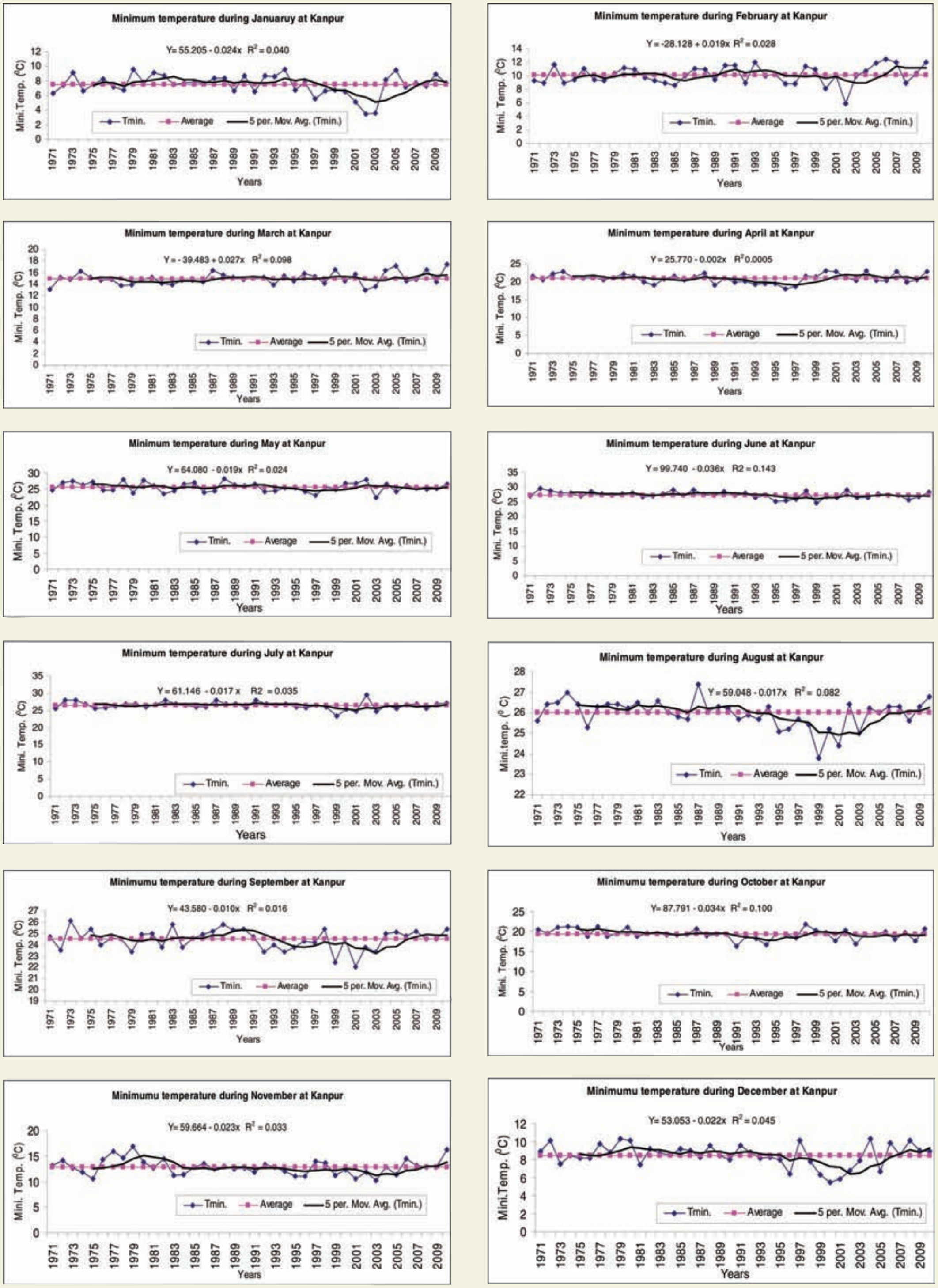


Fig.2.9. Monthly minimum temperature trend at Kanpur (1971-2010)

Decadal changes in minimum temperature

Decadal average minimum temperature of all calendar months during the last four decades (Fig.2.10) showed continuous increasing trend in minimum temperature for the last four decades during February and March months only. In rest of the months, minimum temperature during current decade (2001-10) was either less or on par with the minimum temperature during first two decades (1971-80 and 1981-90).

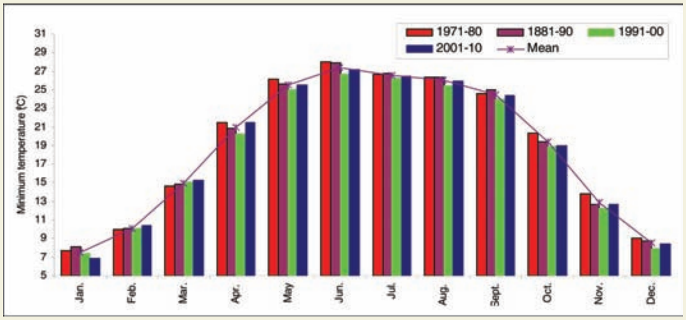


Fig.2.10. Decadal variation in monthly minimum temperature at Kanpur

KOVILPATTI

The normal requirement of rainfall is considered as 20 mm per week for successful crop production. Optimum amount of 20 mm rainfall per week occurs with 67 per cent probability during 42nd standard week when the commencement of Northeast monsoon is expected. It is gradually increasing to 73, 76 per cent during 43rd and 44th standard weeks. If the cropping period commences from 39th standard week, the chances to get 20 mm rainfall is only 56 per cent. The chances are increasing there by to the tune of 76 per cent during 44th standard week. From 45th standard week onwards it starts to decline till 52nd standard week. The 48th and 50th standard weeks are the break weeks where stress may occur (Table 2.8).

Table 2.8. Probability (%) of receiving weekly rainfall of different amounts at Kovilpatti

Std. week	Mean	SD	CV (%)	Probability % for weekly rainfall				
				10 mm	20 mm	30 mm	40 mm	50 mm
1	5.7	23.29	345	45	29	17	8	4
2	8.2	32.56	375	49	37	26	17	11
3	3.5	9.77	345	45	29	17	8	4
4	1.7	3.85	315	2	0	0	0	0
5	3.9	7.29	385	14	1	1	0	0
6	2.7	7.86	315	18	2	1	0	0
7	3.3	10.65	355	26	6	1	1	0
8	8.5	24.16	285	48	32	19	10	5
9	7.0	13.71	192	42	18	5	1	1

Std. week	Mean	SD	CV (%)	Probability % for weekly rainfall				
				10 mm	20 mm	30 mm	40 mm	50 mm
10	3.4	12.55	367	31	1	2	1	1
11	5.7	11.82	225	35	11	2	1	1
12	6.9	14.22	318	35	17	4	1	1
13	5.5	11.35	205	35	11	2	1	0
14	18.8	32.29	180	59	46	36	25	17
15	15.8	29.17	177	58	45	31	20	12
16	17.3	21.69	120	64	47	30	16	8
17	14.4	16.53	118	59	36	17	6	2
18	17.9	21.55	133	61	43	27	14	6
19	14.7	25.13	157	59	44	30	18	9
20	13.2	19.01	126	60	40	22	10	4
21	9.7	18.1	183	50	29	14	5	2
22	11.4	16.4	168	50	27	11	4	1
23	2.7	6.64	220	15	1	0	0	0
24	3.7	12.06	275	32	10	2	1	1
25	3.1	13.58	390	32	12	3	1	1
26	1.3	4.69	315	4	0	0	0	0
27	3.0	7.58	223	2	2	1	0	0
28	3.3	7.50	241	19	2	1	0	0
29	5.5	15.02	314	37	16	5	1	1
30	9.3	21.65	230	49	32	18	8	4
31	2.9	6.87	343	13	1	0	0	0
32	4.3	8.75	167	30	5	1	0	0
33	8.1	16.18	197	46	24	10	3	1
34	9.5	14.37	163	47	22	8	2	1
35	14.1	20.07	154	55	37	21	10	4
36	11.0	21.05	179	53	35	20	10	4
37	13.4	17.28	135	56	34	17	6	2
38	17.0	26.45	156	60	46	32	20	11
39	25.0	29.20	118	69	56	44	31	20
40	23.4	30.16	118	69	57	45	32	22
41	39.7	47.72	125	72	64	56	49	41
42	49.4	80.25	144	71	67	62	57	52
43	56.0	41.03	91	80	73	64	55	46
44	51.0	43.19	85	82	76	68	59	50
45	47.1	55.63	114	75	69	63	56	50
46	27.6	43.88	157	65	57	49	40	31
47	28.7	34.02	130	68	56	46	35	24
48	16.8	27.50	185	61	47	33	21	13
49	19.5	32.31	153	64	51	41	29	20
50	15.6	26.02	183	56	42	28	17	1
51	10.4	18.66	190	50	30	14	6	2
52	9.1	16.00	194	46	23	9	3	1

MOHANPUR

Agricultural drought analysis of two stations Jalpaiguri and Kalimpong was carried out.

Jalpaiguri station: Agricultural drought during *kharif* has appeared in 10 years during the period 1970 to 2006. In most of the years, the agricultural drought was prolonged for three weeks only, whereas in 1985, it prolonged for 20 weeks (Table 2.9). The frequency of *Rabi* season drought is more than the *kharif* season and with a prolonged duration of five weeks.

Table 2.9. Agricultural drought during *Kharif* and *Rabi* season at Jalpaiguri station

Kharif		*Rabi*	
Year	**Week**	**Year**	**Week**
1973	33-36	1970	40-45
1976	35-38	1973	45-50
1982	31-34	1974	43-48
	39-42	1975	41-46
1985	22-25	1976	44-49
	26-29	1980	44-49
	30-33		
	34-37	1983	44-49
	38-41	1984	43-48
		1986	43-48
1986	22-25	1987	45-50
	26-29	1988	44-49
1994	39-42	1989	44-49
1995	27-30	1990	45-50
1996	36-39	1991	42-47
2000	37-40	1993, 1999	43-48
2002	35-38	1994, 2001	45-50
		1996	45-50
		1997	40-45
		1998, 2002	44-49

Kalimpong station: Among 29 years (1969 to 2004, in six years data are erratic), 13 years encountered agricultural drought during *kharif* season, whereas in *Rabi* season, agricultural drought was observed in 21 years (Table 2.10). During *kharif* season, the agricultural drought was continued for nine weeks in many cases, whereas in *Rabi* season it continued for five weeks only (on an average).

Table 2.10. Agricultural drought during *Kharif* and *Rabi* season at Kalimpong station

Kharif		*Rabi*	
Year	**Week**	**Year**	**Week**
1974	38-41	1969	42-47
1975	34-37	1970	41-46
1978	22-25	1973	42-47
	26-29	1974	40-45
	30-33	1980	40-45
	34-37	1981	40-45
1980	22-25	1983	44-49
	32-35	1984	43-48
	36-39	1985	43-48
1981	22-25	1987	45-50
	26-29	1988	40-45
	32-35	1990	40-45
1986	27-30	1991	41-46
	31-34	1992	40-45
1988	31-34	1994	40-45
	37-40	1997	42-47
1989	32-35	2000	40-45
	36-39	2001	41-46
1992	38-41	2002	43-48
1994	39-42		
2000	39-42		

Probability analysis

Two consecutive wet weeks

Jalpaiguri: Probability analysis of two consecutive wet weeks for 10 mm weekly total rainfall showed that more than 75% probability was assured during the period 23rd to 37th SMW. In case of 20 mm rainfall, assured period (75% probability) is 23rd to 37th SMW. For 30 mm weekly total rainfall the same was confined between 25th and 30th SMW. The period of receiving assured rainfall of 40mm (75% probability) is for a short span i.e., from 26th to 29th SMW (Fig.2.11).

Kalimpong: A rainfall amount of 10 mm can be assured (75% probability) at Kalimpong during the period 25th to 35th SMW. In case of 20 mm rainfall, 75 per cent probability of two consecutive weeks occurred at 26th SMW and at 32nd SMW. For 30 mm weekly total rainfall, the same was confined between 26th SMW and 31st SMW. In case of 40mm weekly total rainfall, 70 per cent probability of getting two consecutive wet weeks happened only on 25 and 29th SMW. However, there is a chance (75% probability) for only 10 and 20 mm of weekly total rainfall confining from 24 to 31st SMW and 25th to 35th SMW, respectively (Fig.2.12).

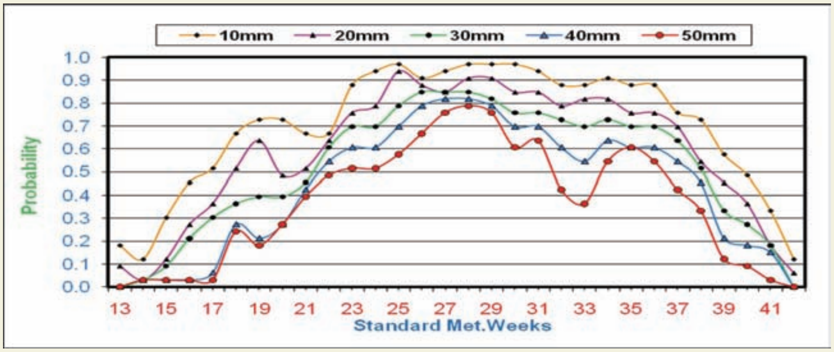


Fig.2.11. Probability of two consecutive wet weeks during 13 to 42 SMW at Jalpaiguri

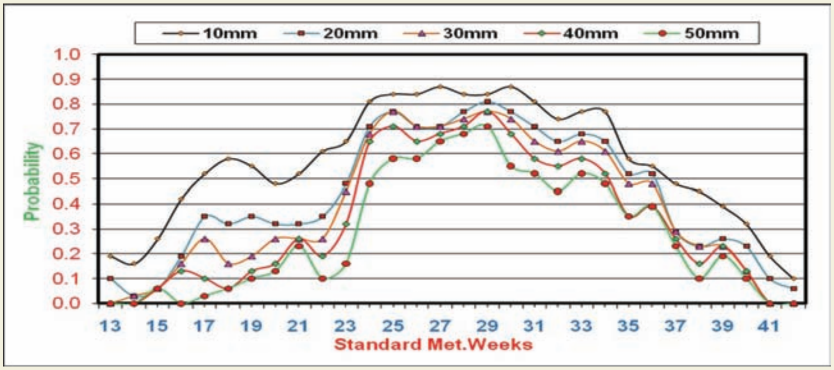


Fig.2.12. Probability of two consecutive wet weeks during 13 to 42 SMW at Kalimpong

Initial and Conditional probability

Jalpaiguri: The chance of receiving 30 mm rainfall (70% probability) is high during the period 23 to 39 SMW and the chance of occurring a wet week followed by wet week is also high (70% probability) during the same period. The probability of a wet week followed by a dry week is about 50 per cent or even more during the period 18 to 37 SMW. This indicates that crop planning during 18 to 21 SMW is somewhat risky as a wet week may likely to be followed by a dry week (Table 2.11).

Table 2.11. Initial and conditional probability of 30 mm weekly total rainfall for Jalpaiguri station

SMW	P(W)	P(W/W)	P(W/D)	SMW	P(W)	P(W/W)	P(W/D)
1	0.00	0.00	0.00	27	0.88	0.93	0.33
2	0.00	0.00	0.00	28	0.91	0.97	0.50
3	0.09	0.00	0.09	29	0.88	0.93	0.33
4	0.00	0.00	0.00	30	0.88	0.93	0.50
5	0.00	0.00	0.00	31	0.85	0.86	0.75
6	0.03	0.00	0.03	32	0.82	0.89	0.40
7	0.03	0.00	0.03	33	0.79	0.89	0.33
8	0.06	0.00	0.06	34	0.85	0.88	0.71
9	0.00	0.00	0.00	35	0.85	0.86	0.80
10	0.00	0.00	0.00	36	0.82	0.82	0.80
11	0.00	0.00	0.00	37	0.85	0.85	0.83
12	0.06	0.00	0.06	38	0.70	0.75	0.40
13	0.27	1.00	0.23	39	0.73	0.74	0.70
14	0.09	0.00	0.13	40	0.48	0.46	0.56
15	0.24	0.33	0.23	41	0.48	0.56	0.41
16	0.33	0.38	0.32	42	0.24	0.38	0.12
17	0.52	0.64	0.45	43	0.06	0.00	0.08
18	0.58	0.59	0.56	44	0.06	0.00	0.06
19	0.55	0.63	0.43	45	0.03	0.00	0.03
20	0.64	0.72	0.53	46	0.03	0.00	0.03
21	0.58	0.62	0.50	47	0.03	0.00	0.03
22	0.67	0.79	0.50	48	0.03	0.00	0.03
23	0.79	0.91	0.55	49	0.00	0.00	0.00
24	0.79	0.88	0.43	50	0.00	0.00	0.00
25	0.82	0.88	0.57	51	0.00	0.00	0.00
26	0.91	0.96	0.67	52	0.03	0.00	0.03

Kalimpong: Compared to Jalpaiguri, the period of receiving 30 mm rainfall with 70 per cent or more probability is shorter and limited to 24^{th} to 31 SMW only (Table 2.12). The chance of a wet week followed by another wet week with 70 per cent or more probability is also limited to the same period. However, the chance of a wet week followed by a dry week is very low during this period indicating a high chance of getting two consecutive wet weeks during this period.

Table 2.12. Initial and conditional probability of 30 mm weekly total rainfall for Kalimpong station

SMW	P(W)	P(W/W)	P(W/D)	SMW	P(W)	P(W/W)	P(W/D)
1	0.03	0.00	0.04	27	0.74	0.88	0.17
2	0.03	0.00	0.03	28	0.77	0.96	0.25
3	0.13	0.00	0.13	29	0.81	0.96	0.29
4	0.03	0.25	0.00	30	0.81	0.96	0.17
5	0.06	1.00	0.03	31	0.81	0.92	0.33
6	0.06	0.00	0.07	32	0.68	0.80	0.17
7	0.00	0.00	0.00	33	0.68	0.90	0.20
8	0.06	0.00	0.06	34	0.74	0.95	0.30
9	0.03	0.00	0.03	35	0.65	0.83	0.13
10	0.00	0.00	0.00	36	0.61	0.75	0.36
11	0.03	0.00	0.03	37	0.65	0.79	0.42
12	0.10	0.00	0.10	38	0.35	0.45	0.18
13	0.16	0.67	0.11	39	0.52	0.64	0.45
14	0.13	0.00	0.15	40	0.29	0.44	0.13
15	0.16	0.25	0.15	41	0.23	0.44	0.14
16	0.26	0.40	0.23	42	0.13	0.00	0.17
17	0.39	0.63	0.30	43	0.00	0.00	0.00
18	0.45	0.67	0.32	44	0.00	0.00	0.00
19	0.35	0.36	0.35	45	0.03	0.00	0.03
20	0.39	0.55	0.30	46	0.03	0.00	0.03
21	0.45	0.67	0.32	47	0.00	0.00	0.00
22	0.39	0.57	0.24	48	0.00	0.00	0.00
23	0.55	0.67	0.47	49	0.00	0.00	0.00
24	0.71	0.82	0.57	50	0.03	0.00	0.03
25	0.81	0.95	0.44	51	0.00	0.00	0.00
26	0.81	0.96	0.17	52	0.06	0.00	0.06

PARBHANI

Long-term (1961-2009) temperature data of Parbhani centre was analyzed for working out trends on extreme events in respect of maximum and minimum temperatures. The days with maximum temperature >40°C and minimum temperature <10°C were respectively considered as high and low temperature related extreme events. The number of

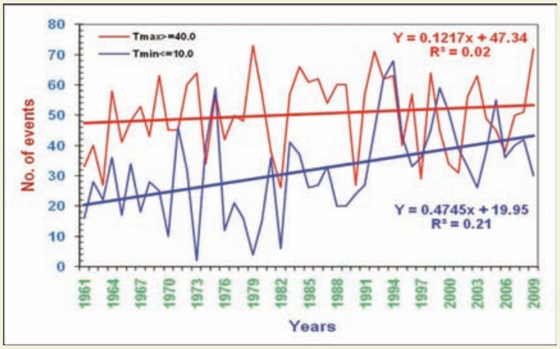


Fig.2.13. Number of extreme events in respect of maximum and minimum temperature at Parbhani

extreme events in respect of maximum and minimum temperature over the last 49 years (Fig.2.13) revealed that the number of events of maximum temperature >40°C are increasing slowly (at the rate of 1 event per decade) while events with minimum temperature <10°C are increasing significantly (5 events per decade). The inter-annual variability of both maximum and minimum temperature related extreme events were high with maximum temperature related extreme events ranging from 72 (highest) in the year 1979 to 26 (lowest) in the year 1982. The minimum temperature related extreme events also varied from 68 (highest) in 1994 to 2 (lowest) in 1973.

RAIPUR

Trends in rainfall during 20th Century

Trends in annual rainfall using long-term (1901-2009) annual rainfall data in respect of 17 districts of Chhattisgarh (Table 2.13) showed a decreasing trend in rainfall in all the districts of the state. However, the declining trend in rainfall was significant in Mahasamund, Raigarh, Kanker and Dhamtari, with 10.8, 5.9, 6.0 and 5.1 mm per year decrease in rainfall, respectively.

Table 2.13. Long-term (1901-2009) rainfall trends in 17 districts of Chhattisgarh

District	Trend (mm/year)	Significance (P-level)
Rajnandgaon	-1.1	NS
Narayanpur	-0.4	NS
Raipur	-1.5	NS
Mahasamund	-10.8	0.01
Raigarh	-5.9	0.05
Koria	-3.4	NS
Korba	-1.9	NS
Janjgir	-1.5	NS
Kawardha	-1.7	NS
Jagdalpur	-2.9	NS
Kanker	-6.0	0.05
Durg	-2.5	NS
Dhamtari	-5.1	0.05
Bilaspur	-0.9	NS
Dantewada	-1.8	NS
Bijapur	-2.3	NS
Ambikapur	-4.0	NS

Rainfall pattern during pre and post-global warming period

To study the impact of global warming on regional rainfall, analysis of rainfall during pre and post-global warming periods, i.e., 1901-70 and 1971-2009 was carried out for all 17 districts of Chhattisgarh. From the analysis (Table 2.14), it was observed that except in Bijapur and Korba districts, the rainfall showed decreasing trend in post-global warming period compared to pre-global warming period. In Bijapur and Korba, the rainfall changed from negative trend in pre-global warming period to positive trend in post-global warming period. In six districts, *viz,* Bilaspur, Durg, Kawardha, Raigarh, Raipur and Rajnandgaon, trend of rainfall changed from positive in pre-global warming period to negative in post-global warming period. In rest of the nine districts, the trends were not reversed in post-global warming period compared to the trends in pre-global warming period.

Table 2.14. Trends (mm/year) in rainfall during pre and post-global warming periods of 17 districts of Chhattisgarh

District	Pre-global warming period (1901-1970)	Post-global warming period (1971-2009)
Ambikapur	-4.6	-4.8
Bilaspur	1.3	-2.4
Bijapur (Bastar)	-0.4	6.6
Dantewada (South Bastar)	5.1	0.61
Dhamtri	-2.4	-2.7
Durg	0.3	-0.1
Jagdalpur	-2.2	-3.2
Janjgir	-	-0.9
Kanker	-2.8	-4.0
Korba	-4.0	4.1
Kawardha	0.9	-4.3
Koria	-1.7	-2.3
Mahasamund	-4.3	-0.8
Raigarh	1.8	-8.8
Narayanpur (Bastar)	3.7	3.7
Raipur	0.8	-4.5
Rajnandgaon	3.2	-8.4

RAKH DHIANSAR

Long-term (38 years) rainfall (*Kharif* and *Rabi*) and mean annual temperature of five locations, *viz*., Jammu, Katra, Batote, Bhaderwah and Banihal of Jammu and Kashmir were analyzed for studying the trends in these climatic variables. From the location-wise trends in mean annual temperature and rainfall during *rabi* and *kharif* seasons (Fig.2.14a-e), it was observed that out of all weather parameters, only mean annual temperature is showing significant increase at all the locations except Jammu. The increasing trend in mean annual temperature at Bhaderwah and Banihal situated at mid to high latitude temperate zone was highly significant. The rainfall in both *rabi* and *kharif* seasons are not showing any significant increasing or decreasing trend at any of the locations except Bhaderwah where *rabi* rainfall is decreasing significantly.

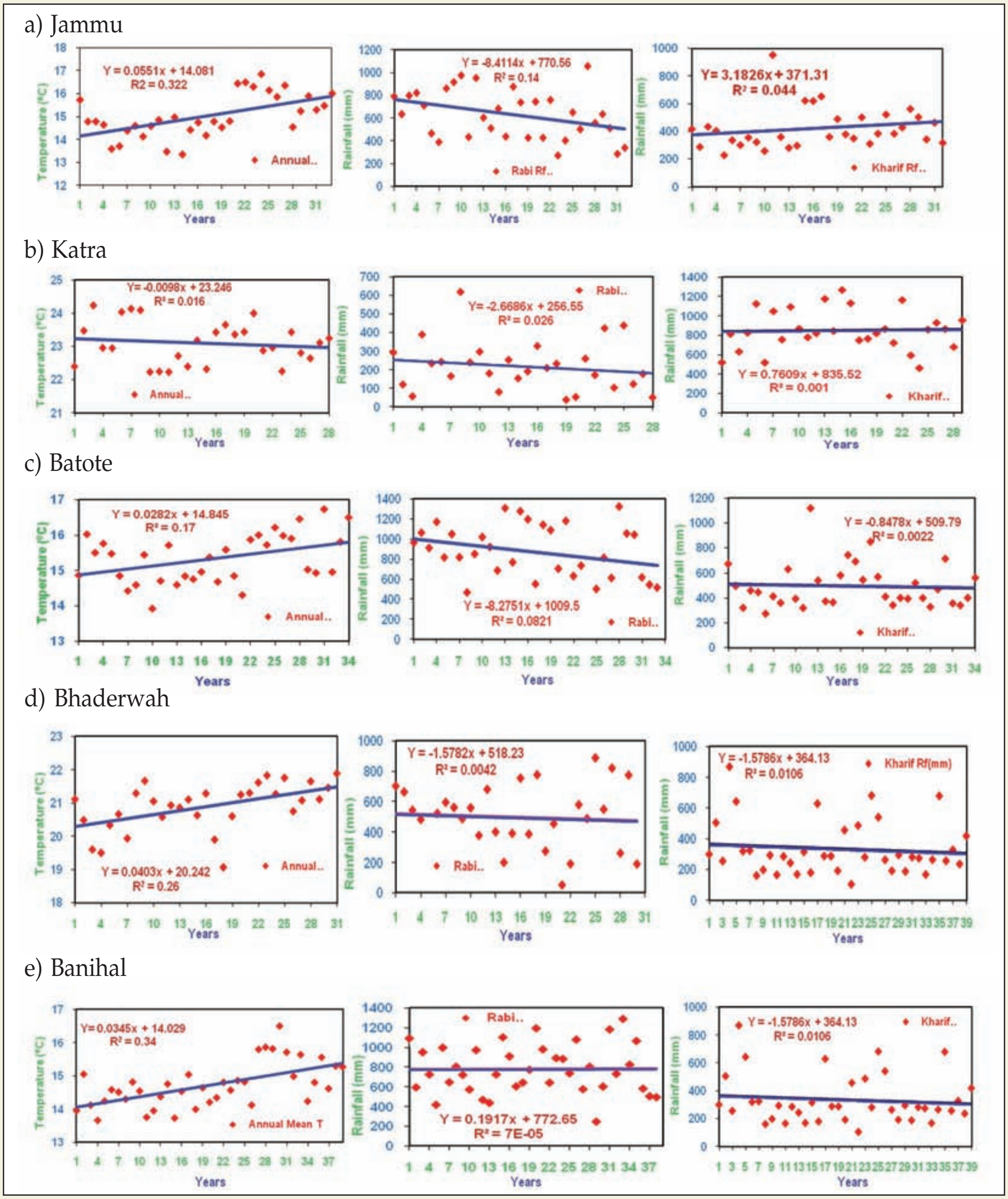


Fig.2.14a-e. Trends in mean annual temperature and seasonal rainfall (Kharif and Rabi) at five locations of Jammu & Kashmir.

RANCHI

Long-term rainfall trends in Agroclimatic Zone-IV and VI are not same (Fig.2.15a & b) and rainfall in Dumka region of Zone-IV is showing increasing trend while rainfall in east Singhbhum region of Zone-VI is showing decreasing trend.

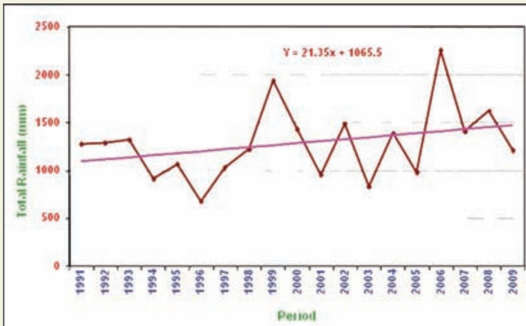


Fig.2.15a. Rainfall pattern in Dumka region of Zone-IV

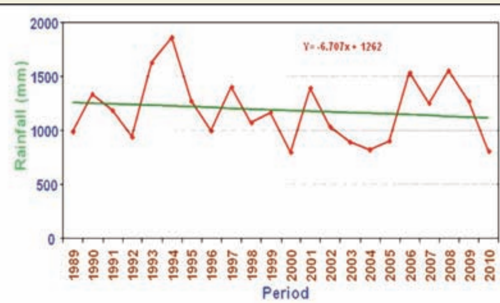


Fig.2.15b. Rainfall pattern in east Singhbhum region of Zone-VI

RANICHAURI

Long-term (1985 to 2009) rainfall data of the mid-Himalayan region of Uttarakhand was analyzed for probability analysis and length of growing period were worked out.

Probability of analysis

At 50 per cent or more probability, wet week of 20 mm or more rainfall occurs during 25 to 27 SMW (Fig.2.16). Conditional probability (> 50%) of receiving wet week followed by wet week of 20 and 30 mm rainfall is confined to 25-37 and 26-37 SMW, respectively.

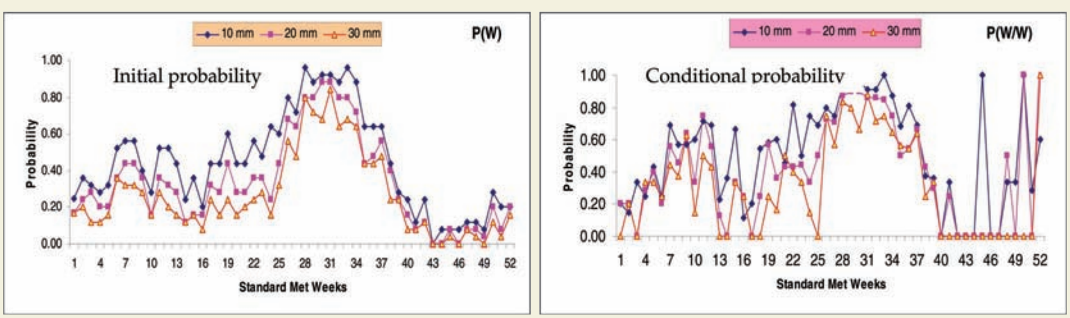
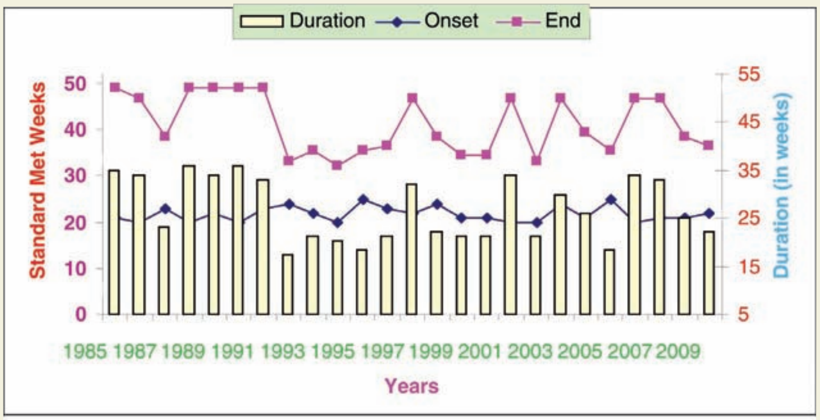


Fig.2.16. Initial and conditional probabilities for various assured amount of rainfall at Ranichauri

Length of growing period

Utilizing weekly water balance studies for the period (1985-2009), start, end and the length of growing period (LGP) were worked out (Fig.2.17). The rainy season can commence as early as by 20 SMW and as late as in 25 week with the average commencement of start in

22 SMW. The end of rainy season is most erratic and the earliest and latest week of cessation of season is 36 and 52 SMW, respectively. Mean duration of the season was worked out to be 23 weeks and it can vary from 13 to 32 weeks across different years.



Mean Start	..	22	Earliest	..	20	Latest	..	25	SD	..	1.7
Mean End	..	45	Earliest	..	36	Latest	..	52	SD	..	6.1
Mean Duration	..	23	Min Duration	..	13	Max Duration	..	32	SD	..	6.7

Fig.2.17. Characterization of the length of growing period in Mid Himalayan region of Uttarakhand

SAMASTIPUR

Long-term rainfall data of Motihari (1969-1977) and Gaya (1969-2003) districts of Zone-I and Zone-IIIB regions of Bihar were analyzed for working out rainfall characteristics, probabilities of rainfall and LGP in these districts.

Rainfall

Motihari district received higher rainfall (1311.2 mm) than Gaya (1112.1 mm) district. Monthly rainfall characteristics at Motihari and Gaya districts, (Table 2.15) showed that July is the month with highest rainfall of 377.6 and 316.3 mm respectively, at both the districts. The coefficient of variation, however, was lowest in June (49.4%) at Motihari and in July (39.1%) at Gaya districts. All the months of southwest monsoon season received more than 150 mm of rainfall with coefficient of variation less than 100 per cent (except September at Motihari) in both the districts. Though 157.7 mm of mean rainfall is received at Motihari in September, it was erratic with CV of 103.9 per cent. At Motihari, substantial amount of rainfall (144.9 mm) occurs in pre-monsoon month of May.

Table 2.15. Minimum, maximum, mean and standard deviation and coefficient of variation of weekly rainfall at Motihari and Gaya

Month	Motihari				Gaya			
	Rainfall (mm)			CV (%)	Rainfall (mm)			CV (%)
	Minimum	Maximum	Mean		Minimum	Maximum	Mean	
January	0.0	53.0	11.1	130.1	0.0	74.9	17.3	1221.1
February	0.0	52.2	14.8	112.3	0.0	63.3	14.7	123.8
March	0.0	56.9	8.6	141.1	0.0	68.0	10.4	149.9
April	0.0	263.6	42.3	138.7	0.0	102.2	13.2	154.2
May	0.0	835.4	144.9	137.4	0.0	123.0	26.4	118.1
June	37.7	453.8	240.7	49.4	17.8	411.4	155.2	72.3
July	61.8	847.6	377.6	61.0	113.5	599.6	316.3	39.1
August	0.0	752.4	268.2	63.5	65.9	647.3	292.3	46.2
September	0.0	612.5	157.7	103.9	43.1	579.0	198.2	53.3
October	0.0	195.8	32.1	156.3	0.0	210.7	57.4	104.3
November	0.0	64.0	9.3	196.6	0.0	48.5	6.9	211.6
December	0.0	40.6	3.9	229.8	0.0	32.9	3.8	194.8

Duration of rainy season

The year-wise and mean start, end and duration of southwest monsoon season at Motihari and Gaya districts (Table 2.16) brought out that though end and duration of season is same (42 and 17 weeks) at both the districts, onset is one week early at Motihari (25th) than at Gaya (26th week). The onset is as early as in 24th SMW and as late as in 28th SMW at both the districts. The end, however, varied from 33rd to 52nd SMW at Moltihari and from 36th to 52nd SMW at Gaya. Similarly, the duration of rainy season varies from 8 to 28 weeks at Motihari and 10 to 27 weeks at Gaya districts.

Probability of weekly rainfall

The expected weekly rainfall at 75 and 50 per cent probability levels in Motihari and Gaya districts (Table 2.17) brought out that rainfall of 20 mm or more occurs with 75 per cent probability only in two isolated weeks 25th and 31st SMW of the year in Motihari district. Gaya district, however, receives rainfall of 20 mm or more with 75 percent probability during 27th to 33rd SMW. At 50 per cent probability, rainfall of 20 mm or more is received from 22nd to 37th SMW in Motihari district and from 25th to 38th SMW in Gaya district.

Table 2.16. Start, end and duration of rainy season at Motihari and Gaya districts of Bihar

Year	Motihari district			Gaya district		
	Start week	End week	Duration	Start week	End week	Duration
1969	25	33	8	27	45	18
1970	24	40	16	24	40	16
1971	25	41	16	26	42	16
1972	25	43	18	27	47	20
1973	25	39	14	24	38	14
1974	25	39	14	27	42	15
1975	24	41	17	26	41	15
1976	25	33	8	24	38	14
1977	24	52	28	26	51	25
1978	24	40	16	24	43	19
1979	24	48	24	26	48	22
1980	24	42	18	25	42	17
1981	25	39	14	27	39	12
1982	26	36	10	28	45	17
1983	24	48	24	26	43	17
1984	25	38	13	24	36	12
1985	24	43	19	27	42	15
1986	24	46	22	26	40	14
1987	25	37	12	26	36	10
1988	25	36	11	25	43	18
1989	25	52	27	24	50	26
1990	25	39	14	24	39	15
1991	24	52	28	24	38	14
1992	28	41	13	28	39	11
1993	25	44	19	27	43	16
1994	27	47	20	25	40	15
1995	25	46	21	25	52	27
1996	26	40	14	25	39	14
1997	25	50	25	26	48	22
1998	-	-	-	27	42	15
1999	-	-	-	24	42	18
2000	-	-	-	24	38	14
2001	-	-	-	25	40	15
2002	-	-	-	26	42	16
2003	-	-	-	26	43	17
Mean	**25**	**42**	**17**	**26**	**42**	**17**

Table 2.17. Weekly rainfall expected at 75 and 50 per cent probabilities in Motihari and Gaya districts

Week	Weekly precipitation (mm) for the probabilities					
	Motihari (Database: 29 Years)			Gaya (Database: 35 Years)		
	75 Percent	50 Percent	Mean (mm)	75 Percent	50 Percent	Mean (mm)
1	0.7	1.9	2.0	0.9	2.5	3.2
2	0.8	2.0	2.1	0.9	2.2	2.3
3	1.0	2.7	3.4	0.8	3.2	5.5
4	0.7	1.9	2.0	0.9	2.9	4.2
5	0.7	2.1	2.4	1.1	3.1	4.0
6	0.0	5.6	5.6	0.3	3.1	3.1
7	0.0	5.3	5.3	0.0	3.8	3.8
8	0.0	2.8	2.8	0.0	3.6	3.6
9	0.8	1.6	1.1	0.8	2.8	4.1
10	1.1	2.2	1.9	1.0	2.5	2.7
11	0.7	1.4	0.8	0.7	1.4	0.8
12	0.9	2.4	2.9	0.8	2.1	2.2
13	1.0	2.6	3.0	0.7	2.4	3.2
14	0.8	2.6	3.6	0.7	1.7	1.4
15	1.4	6.1	12.1	0.8	1.9	1.8
16	1.6	6.6	12.5	0.8	3.5	6.5
17	1.5	6.0	11.3	0.8	2.2	2.5
18	2.7	8.9	14.8	0.7	2.7	4.3
19	2.3	14.6	40.2	1.0	3.6	5.6
20	2.9	13.0	27.5	1.3	4.9	8.4
21	4.2	15.6	29.3	1.3	4.2	6.1
22	8.1	29.2	54.1	1.3	4.7	8.1
23	9.8	30.9	52.0	2.8	11.7	23.4
24	13.0	32.9	48.0	5.0	17.5	31.2
25	29.7	56.3	69.2	7.5	21.1	32.9
26	16.6	46.7	73.6	17.9	46.1	68.4
27	19.2	56.0	90.6	26.0	62.8	89.7
28	17.3	57.3	101.0	26.9	55.1	71.0
29	15.8	43.5	67.4	33.0	57.4	67.3
30	14.8	44.7	73.6	20.1	46.4	64.1
31	22.4	64.6	103.9	34.5	61.4	72.9
32	18.2	40.4	54.3	30.6	54.2	64.0
33	9.8	27.5	42.9	40.0	37.8	78.5
34	12.5	32.8	48.9	15.7	36.7	50.9
35	9.5	30.7	53.0	16.7	42.9	63.5
36	5.4	21.0	40.8	25.0	52.1	67.6

Week	Weekly precipitation (mm) for the probabilities					
	Motihari (Database: 29 Years)			Gaya (Database: 35 Years)		
	75 Per cent	50 Per cent	Mean (mm)	75 Per cent	50 Per cent	Mean (mm)
37	5.5	26.9	62.2	10.0	28.3	44.3
38	3.1	12.4	23.8	7.2	23.7	41.0
39	2.7	10.6	20.1	4.5	15.1	26.2
40	1.3	8.4	22.4	2.0	10.8	25.9
41	0.8	3.6	6.7	1.0	4.1	7.3
42	0.7	1.8	1.5	1.0	5.8	14.0
43	0.7	1.5	1.0	0.9	4.5	10.0
44	0.7	2.2	2.8	0.8	1.3	0.4
45	0.7	0.9	0.0	0.6	2.2	3.2
46	0.6	2.0	2.9	0.6	1.3	0.7
47	0.6	1.5	1.1	0.6	1.7	1.8
48	0.6	2.1	3.1	0.6	1.5	1.2
49	0.7	1.2	0.4	0.7	1.2	0.3
50	0.6	1.5	1.2	0.7	1.6	1.2
51	0.8	1.2	0.4	0.7	1.4	0.8
52	0.7	1.8	1.8	0.6	1.6	1.4
Annual	**1033**	**1274**	**1311**	**922**	**1092**	**1112**

Initial and conditional probabilities of rainfall

The initial and conditional probabilities of wet week (P[W]) of 30 and 40 mm rainfall and wet week followed by wet week (P[W/W]) during all 52 weeks of the year in Motihari and Gaya districts (Table 2.18) showed that rainfall of 30 mm at 50 per cent and more probability (wet weeks) is received continuously during 23-25, 27-32 and 34-35 SMW at Motihari and from 26-36 weeks at Gaya district. Rainfall of 40 mm occurred with 50 per cent or more probability continuously for 2 or 3 weeks during 27-28 and 30-32 weeks only at Motihari while it occurred continuously during 26-33 weeks at Gaya district. Wet week followed by wet week with 30 mm weekly rainfall also occurred during the same weeks at Motihari and Gaya districts. Wet week of 40 mm rainfall followed by wet week of same rainfall occurred continuously during 28-32 SMW at Motihari and 26-33 weeks at Gaya district.

Table 2.18. Initial and conditional probabilities of rainfall at Motihari and Gaya districts

Week	Probabilities							
	Motihari				Gaya			
	Initial		Conditional		Initial		Conditional	
	30 mm	40 mm	30 mm	40 mm	30 mm	40 mm	30 mm	40 mm
1	0.00	0.00	0.00	0.00	0.03	0.03	1.00	0.0
2	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.0
3	0.00	0.00	0.00	0.00	0.09	0.06	0.00	0.0
4	0.00	0.00	0.00	0.00	0.06	0.03	1.00	0.0
5	0.03	0.03	0.00	0.00	0.00	0.00	1.00	0.0
6	0.10	0.07	0.00	0.00	0.00	0.00	0.00	0.0
7	0.07	0.03	0.00	0.00	0.06	0.03	0.00	0.0
8	0.00	0.00	0.00	0.00	0.06	0.00	1.00	0.0
9	0.00	0.00	0.00	0.00	0.06	0.00	1.00	0.0
10	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.0
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
12	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.0
13	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.0
14	0.07	0.00	0.00	0.00	0.00	0.00	1.00	0.0
15	0.14	0.07	0.00	0.00	0.03	0.00	0.00	0.0
16	0.17	0.10	0.25	0.50	0.09	0.09	0.00	0.0
17	0.14	0.14	0.00	0.00	0.03	0.00	1.00	0.0
18	0.14	0.10	0.50	0.25	0.09	0.03	1.00	0.0
19	0.31	0.21	0.50	0.33	0.06	0.03	1.00	0.0
20	0.31	0.21	0.44	0.17	0.09	0.57	0.50	0.0
21	031	0.28	0.56	0.83	0.06	0.00	1.00	0.0
22	0.41	0.31	0.44	0.50	0.09	0.06	0.00	0.0
23	0.55	0.45	0.75	0.78	0.23	0.17	0.67	0.50
24	0.52	0.38	0.56	0.38	0.37	0.31	0.63	0.67
25	0.79	0.76	0.87	0.73	0.34	0.26	0.46	0.45
26	0.45	0.41	0.43	0.41	0.71	0.57	0.75	0.78
27	0.69	0.59	0.62	0.42	0.77	0.74	0.84	0.80
28	0.72	0.69	0.70	0.71	0.71	0.63	0.70	0.62
29	0.52	0.48	0.57	0.55	0.77	0.66	0.80	0.68
30	0.69	0.55	0.67	0.64	0.69	0.66	0.59	0.52
31	0.72	0.69	0.70	0.3	0.74	0.63	0.79	0.74
32	0.69	0.55	0.81	0.60	0.77	0.69	0.85	0.77
33	0.41	0.34	0.35	0.31	0.80	0.77	0.81	0.79

Week	Probabilities							
	Motihari				Gaya			
	Initial		Conditional		Initial		Conditional	
	30 mm	40 mm	30 mm	40 mm	30 mm	40 mm	30 mm	40 mm
34	0.52	0.52	0.50	0.60	0.63	0.46	0.57	0.44
35	0.52	0.41	0.53	0.47	0.63	0.51	0.73	0.56
36	0.38	0.34	0.40	0.33	0.71	0.63.	0.64	0.61
37	0.55	0.41	0.82	0.60	0.46	0.34	0.48	0.45
38	0.38	0.21	0.56	0.42	0.40	0.37	0.56	0.58
39	0.28	0.14	0.27	0.17	0.37	0.26	0.50	0.31
40	0.27	0.21	0.25	0.50	0.29	0.29	0.38	0.44
41	0.10	0.07	0.17	0.17	0.06	0.03	0.00	0.00
42	0.00	0.00	0.00	0.00	0.17	0.11	0.50	0.00
43	0.00	0.00	0.00	0.00	0.11	0.11	0.17	0.00
44	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.00
46	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00
47	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00
48	0.03	0.03	0.00	0.00	0.08	0.00	0.00	0.00
49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00

SOLAPUR

Long-term (50 years) rainfall data of nine locations in the scarcity zone of Maharashtra were analyzed to work out rainfall characteristics, probabilities, length of growing season and drought frequencies in this zone.

Annual rainfall

Analysis of annual rainfall and its variability at nine locations spread across north, central and southern parts of the scarcity zone (Table 2.19) brought out that average annual rainfall over central part was lowest (503.3 mm) and was highest over southern part (636.3 mm). The variability of annual rainfall (CV) at Chas in central part was highest (41%) and the variability at Dhule in northern part was the lowest.

Table 2.19. Annual rainfall (mm) and rainfall variability in scarcity zone of Maharashtra

Zone	Name of the center	Rainfall	Highest	Lowest	CV (%)
Northern Part	Dhule	613.4	856.4	332.5	25
Average		613.4			
Central Part	Kopergaon	447.5	852.2	151.6	39
	Rahuri	550.4	896.4	267.1	32
	Chas	511.6	1061.9	30.3	41
Average		503.2			
Southern Part	Jeur	577.9	1044	234.6	35
	Mohol	635.4	1270	277.1	31
	Pandharpur	599.9	1118	241.5	37
	Padegaon	508.8	783.5	114.0	30
	Solapur	731.8	1292.4	270.3	29
Average		**636.3**			
Zonal Average		**575.3**			

Seasonal rainfall

Seasonal rainfall in all the four major seasons at 9 locations of scarcity zone (Table 2.20) indicated that at all the locations; southwest monsoon season received highest rainfall with lowest CV compared to other seasons. The rainfall during southwest monsoon season was highest at Solapur (550.5 mm) of southern part and lowest at Kopergaon (344.8 mm) of central part. The coefficient of variation in rainfall of southwest monsoon was lowest (30%) at Dhule of northern part and highest at Chas (46%) of central part. Contribution of rainfall by northeast monsoon was highest (135.7 mm) at Pandharpur and lowest (70.8 mm) at Dhule. The rainfall from northeast monsoon season was higher and less variable (CV < 75%) at all the locations in southern part of the zone compared to locations in central and northern parts.

Table 2.20. Seasonal rainfall (mm) and rainfall variability CV (%) in scarcity zone of Maharashtra

Season	Dhule		Kopergaon		Rahuri		Chas		Jeur		Mohol		Pandharpur		Padegaon		Solapur	
	RF	CV	RF	CV	RF	CV	RF	CV	RF	CV	RF	CV	RF	CV	RF	CV	RF	CV
Hot weather (Mar- May)	19.6	122	20.3	135	26.9	114	33.4	133	37.3	99	57.3	85	55.9	52	43.2	80	56.7	72
South west (Jun- Sept)	517.5	30	344.8	38	407.6	35	371.3	46	422.8	44	453.7	41	402.8	43	352.8	41	550.5	34
North east (Oct- Dec)	70.8	88	77.8	102	110	83	103.2	84	113.6	62	116.6	60	135.7	73	110.6	72	117.9	64
Winter (Jan- Feb)	5.5	151	4.6	220	5.9	192	3.7	268	4.2	225	7.8	166	5.5	175	2.2	193	6.7	178
Total	**613.4**		**447.5**		**550.4**		**511.6**		**577.9**		**635.4**		**599.9**		**508.8**		**731.8**	

Weekly rainfall probability

Probability of wet week (P[W]} and conditional probability of wet week followed by wet week (P[W/W]) at all nine locations (Table 2.21) showed that no week had initial probability of more than 70 per cent at any of the locations. In other words, rainfall is not dependable in any of the week at any of these locations. In northern part at Dhule, probability of getting wet week was more than 50 per cent only in 24 to 26, 28, 30, 31, 34 and 35 SMW. The conditional probability of more than 50 per cent was only in four isolated weeks 24, 25, 30 and 35 SMW. The results indicated that in this region *kharif* crops can only be sown with risk of encountering terminal stress conditions.

Table 2.21. Initial P(W) and conditional P(W/W) probabilities of getting weekly rainfall of 20 mm or more in scarcity zone of Maharashtra

SMW	Dhule		Kopergaon		Rahuri		Chas		Jeur		Mohol		Pandharpur		Padegaon		Solapur	
	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	0	3	0	0	0	0	0	2	0	3	0	5	0	0	0	0	0
3	0	0	3	0	3	0	0	0	2	0	0	0	0	0	0	0	3	0
4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
6	0	0	0	0	3	0	2	0	0	0	0	0	5	0	0	0	0	0
7	0	0	0	0	0	0	2	0	0	0	3	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
9	0	0	3	0	0	0	2	0	0	0	3	0	0	0	0	0	2	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	5	0	0	0	0	0	2	0	2	0	3	0	5	0	0	0	5	0
14	0	0	0	0	0	0	2	0	2	0	5	0	10	0	3	0	7	0
15	3	0	6	0	3	0	7	0	0	0	0	0	10	0	3	0	5	0
16	0	0	0	0	3	0	2	0	2	0	0	0	0	0	3	0	2	0
17	3	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	3	0
18	3	0	3	0	3	0	5	0	2	0	5	0	10	0	0	0	5	0
19	5	0	6	0	6	0	5	0	7	0	13	0	10	0	9	0	8	40
20	0	0	6	50	6	50	5	0	7	0	13	20	10	0	14	33	20	25
21	0	0	6	0	10	0	9	50	12	0	23	60	19	0	20	40	14	25
22	18	0	23	50	13	0	20	50	28	20	23	11	24	0	31	43	31	28
23	35	43	37	88	39	100	36	78	35	58	38	33	43	40	40	36	46	44
24	53	64	49	46	61	42	34	25	35	33	48	33	43	56	46	50	46	41
25	55	57	26	29	26	26	25	53	30	20	23	21	19	11	31	38	41	29

SMW	Dhule		Kopergaon		Rahuri		Chas		Jeur		Mohol		Pandharpur		Padegaon		Solapur	
	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP	IP	CP
26	55	36	49	44	23	0	25	27	35	31	30	44	48	100	26	18	39	48
27	45	50	29	24	29	29	20	9	19	27	20	17	24	20	17	11	39	48
28	50	44	34	30	35	22	23	11	21	50	25	38	29	40	31	50	41	50
29	45	50	31	42	29	27	23	40	30	33	25	40	14	17	29	45	47	75
30	50	61	37	45	26	33	23	50	33	54	33	40	29	100	29	40	61	56
31	53	45	31	46	29	63	25	50	23	43	38	62	29	33	29	50	42	36
32	45	52	20	27	19	22	18	18	26	40	38	29	38	17	14	10	44	50
33	45	61	20	43	13	17	16	25	19	45	25	36	24	38	17	40	41	42
34	50	44	26	43	29	50	25	43	26	38	35	60	24	40	11	0	39	39
35	50	70	29	22	35	44	27	27	33	45	38	50	33	40	23	25	36	57
36	38	50	31	70	29	55	34	42	28	43	33	47	38	43	23	63	44	46
37	40	33	37	55	32	44	52	67	42	67	45	46	43	50	37	88	46	67
38	40	56	40	46	52	80	66	70	65	67	63	72	43	33	54	69	61	67
39	43	69	51	64	65	69	45	52	60	64	60	64	57	56	69	84	63	59
40	45	29	26	22	42	45	43	50	47	54	53	63	57	58	54	58	49	48
41	15	30	20	22	26	38	25	42	35	40	40	43	29	50	31	37	36	43
42	8	0	14	43	16	25	20	18	26	40	28	44	29	33	17	27	32	26
43	8	0	17	0	13	0	14	11	19	9	20	27	14	17	17	17	22	15
44	10	33	6	33	6	0	11	33	7	13	8	13	10	0	9	0	12	14
45	5	0	6	0	6	0	7	20	14	0	20	0	5	0	14	0	12	0
46	8	0	3	0	13	0	16	33	9	0	5	0	5	0	9	20	8	20
47	3	0	9	0	6	0	5	14	7	0	10	0	10	0	6	33	5	33
48	8	0	11	0	10	50	11	50	5	33	5	50	0	0	9	100	3	0
49	5	33	3	0	6	33	7	40	2	0	8	50	5	0	9	33	2	0
50	5	0	3	0	3	0	5	0	7	0	5	0	5	0	3	0	5	0
51	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	0	6	0	3	0	0	0	2	0	5	0	10	0	0	0	3	0

(IP = Initial Probability, P (W); CP = Conditional Probability, P (W/W))

In central part, probability of receiving rainfall of 20 mm was more than 50 per cent only in 24 SMW during *kharif* season and 38 SMW during *rabi* season at Rahuri. In *rabi* season, the probability of receiving rainfall of 20 mm was also more than 50 per cent in 38 SMW at Chas and 39 SMW at Kopergaon. These results indicated the possibility of sowing *rabi* season crops in 38 SMW at Rahuri and Chas and in 39 SMW at Kopergaon.

In southern part, the initial and conditional probabilities of receiving wet week of 20 mm or more are more than 50 per cent during 37-39 SMW at Jeur and Solapur; 38 to 40 SMW at Mohol and Padegaon and 39 to 40 SMW at Pandharpur. These probabilities brought out that only sowing of *rabi* crops is possible in this part of the scarcity zone.

Agroclimatic characterization at micro-level

For micro-level (Tehsil level) agroclimatic characterization, rainfall data for last five decades from 10 tehsils of Solapur district were analyzed.

Annual and seasonal rainfall

Annual as well as seasonal rainfall and rainy days of four seasons, *viz.*, southwest monsoon, northeast monsoon, winter and summer, in respect of 10 tehsils of Solapur district (Table 2.22) revealed that annual rainfall and rainy days across tehsils ranged from 584 mm at Malshiras to 717 mm at Akalkot and 30 days at Malshiras to 43 days at Solapur, respectively. The coefficient of variability in rainfall and rainy days was lowest at Barshi district while it was highest in rainfall and rainy days at Malshiras and Mohol districts, respectively.

Table 2.22. Average annual and seasonal rainfall (mm) and its variability in different Tehsils of Solapur district of Maharashtra

Tehsil	Annual		Southwest		Northeast		Winter		Summer	
	Rainfall	Rainy	Rainfall	Rainy days	Rainfall	Rainy days	Rainfall	Rainy days	Rainfall	Rainy days
Akkalkot	717(32.2)	42(30.2)	547(36.5)	30(27.9)	123(74.3)	7(68.3)	4(224.7)	0(261.1)	43.4(91.1)	3(111.3)
Barshi	687(27.8)	41(21.5)	540(35.1)	31(22.7)	103(70.8)	6(53.7)	2(266.8)	0(323.8)	42.2(86.1)	2(149.4)
Karmala	597(40.9)	33(30.0)	449(48.2)	24(28.4)	111(74.7)	6(64.7)	1(281.0)	0(323.8)	36.3(120.7)	2(103.1)
Madha	619(31.5)	36(28.7)	45937.3)	26(29.8)	121(72.0)	6(60.3)	3(264.5)	0(272.4)	36.7(97.4)	2(127.1)
Malshiras	584(50.4)	30(28.9)	427(55.6)	22(30.2)	133(95.8)	6(60.0)	3(523.5)	0(369.5)	20.4(164.2)	1(233.0)
Mangalwedha	612(33.2)	34(27.5)	444(41.1)	24(26.2)	122(81.4)	6(61.5)	6(195.5)	0(252.6)	40.9(93.5)	3(107.4)
Mohol	588(31.2)	36(31.7)	448(37.3)	27(27.0)	97(60.7)	6(59.2)	5(240.2)	0(243.8)	38.3(119.7)	2(146.4)
Pandharpur	651(38.5)	36(31.0)	483(44.9)	27(28.7)	131(86.2)	6(62.2)	2(222.0)	0(319.9)	35.5(99.6)	2(131.8)
Sangola	677(37.5)	36(29.2)	469(37.2)	24(26.3)	154(84.3)	7(57.9)	1(328.4)	0(369.5)	54.4(101.3)	4(93.8)
Solapur	716(31.5)	43(24.5)	533(36.4)	31(26.8)	119(70.1)	6(64.1)	7(163.0)	0(167.8)	57.0(71.7)	4(75.4)

(Figures in parenthesis are coefficient of variability)

Probability of weekly rainfall

The weekly rainfall expected at probability levels 50 and 75 per cent at 10 Tehsils of Solapur district (Table 2.23) brought out that at 75 per cent probability, none of the Tehsils are expected to receive more than 20 mm rainfall in any of the 52 weeks of a year. At 50 per cent probability also very few weeks receive more than 20 mm rainfall at all the Tehsils of the district. None of the Tehsils except Malshiras is receiving more than 20 mm rainfall in 23 to 24 weeks, the start of the *kharif* season and are not suitable for sowing of *kharif* crops. The Tehsils Akkalkot and Barshi receiving more than 20 mm rainfall (at 50% probability) during 30 to 31 SMW are suitable for sowing of short duration *kharif* crops or fodder. All the Tehsils receiving optimum rainfall for sowing (> 20 mm) for 2 to 4 weeks continuously during 37 to 40 SMW are suitable for sowing of *rabi* crops.

Table 2.23. Weekly rainfall (mm) received at 75 and 50 per cent probabilities in different tehsils of Solapur district of Maharashtra.

Tehsils and Probability (%) levels							
Karmala		Madha		Malshiras		Mangalwedha	
75	50	75	50	75	50	75	50
0.8	1.1	0.7	0.9	0.7	0.9	0.9	1.0
0.7	1.4	0.8	1.3	0.7	0.9	0.8	1.7
0.7	1.5	0.7	0.9	0.9	1.1	0.7	1.3
0.7	0.9	0.7	0.9	0.7	0.9	0.7	0.9
0.8	1.2	0.7	0.9	0.9	1.1	0.9	1.0
0.0	0.7	0.0	0.3	0.3	0.0	0.3	0.1
0.3	0.1	0.3	0.0	0.3	0.0	0.3	0.0
0.0	0.7	0.0	0.9	0.0	0.6	0.4	0.1
0.3	0.0	0.8	2.0	0.8	1.4	0.9	2.0
0.8	1.1	0.9	1.6	0.9	1.1	0.8	1.1
0.7	1.6	0.9	1.1	0.7	0.9	0.9	1.1
0.8	1.1	0.9	1.3	0.8	1.4	0.0	0.0
0.8	1.4	0.9	2.5	0.8	1.2	0.8	1.2
1.0	3.7	1.0	2.4	0.9	2.2	0.9	2.6
1.1	3.2	1.1	2.5	0.9	2.1	0.8	1.9
0.9	1.3	0.8	1.7	0.8	1.4	0.9	1.5
1.1	2.8	1.0	1.7	0.8	1.6	0.9	1.6
1.1	3.9	1.2	4.4	0.8	2.8	1.1	4.0
0.9	2.2	1.2	3.2	0.9	2.4	1.0	2.7
1.2	3.9	1.2	3.4	1.1	3.8	1.7	4.1
1.6	5.9	1.9	5.7	1.6	6.3	1.3	4.5
2.0	6.6	2.7	8.8	1.5	6.0	2.0	7.8
4.7	14.9	5.9	16.0	4.9	16.3	4.4	13.6

Tehsils and Probability (%) levels							
Karmala		Madha		**Malshiras**		**Mangalwedha**	
75	**50**	**75**	**50**	**75**	**50**	**75**	**50**
6.1	19.1	9.4	22.9	5.7	17.0	4.4	13.6
3.9	12.3	4.1	14.2	1.6	7.1	2.9	9.3
3.6	11.5	4.9	13.3	4.4	12.4	4.9	14.6
5.0	16.1	5.2	16.0	3.5	12.0	2.7	10.2
4.0	15.1	6.2	16.9	3.5	13.0	2.9	10.1
3.9	15.4	4.6	15.5	2.9	9.6	2.8	11.0
7.9	23.4	9.5	24.0	4.0	12.4	6.9	17.8
5.9	20.4	6.3	20.2	4.2	11.9	5.0	15.7
5.7	16.4	5.8	15.8	3.9	11.7	4.4	13.5
4.8	17.1	3.7	12.1	2.2	9.0	3.4	9.5
4.8	16.8	4.2	17.3	2.3	11.9	3.0	13.3
3.9	13.3	5.3	17.7	3.8	15.0	3.2	12.9
5.8	19.2	5.5	20.0	4.2	16.7	4.2	14.1
5.8	23.1	5.0	19.2	3.7	16.1	4.2	19.0
10.0	30.2	10.8	31.1	8.5	26.9	13.5	34.6
5.6	22.9	10.3	30.2	7.3	26.3	8.8	29.7
5.1	18.1	5.3	14.9	4.4	14.9	5.7	18.0
2.8	13.0	2.6	12.0	2.8	12.9	2.9	12.5
1.3	5.4	1.2	5.5	1.3	5.5	1.7	8.0
1.2	5.6	1.1	5.0	1.2	5.7	1.1	6.1
1.3	5.1	1.5	3.8	1.1	3.6	1.1	4.5
		2.1	1.3	5.4	3.6	1.2	3.6
1.1	4.2	1.2	3.6	1.2	4.2	1.2	5.3
0.9	2.6	1.0	2.7	1.0	3.3	0.7	2.2
0.9	3.6	1.0	2.8	0.9	3.8	0.8	2.2
0.8	2.3	0.9	2.4	0.7	2.2	0.6	2.0
0.8	1.2	0.9	2.2	0.8	2.0	0.8	1.6
0.8	1.1	0.9	1.4	0.9	1.1	0.9	1.1
0.7	0.9	0.7	0.9	0.8	1.3	0.8	1.4

Meteorological drought

Based on annual rainfall deficit from normal, years were classified as mild, moderate and severe droughts when rainfall deficit was upto 25, 26-50 and more than 50 per cent, respectively. Years were classified as no drought years when rainfall was more than normal. Different categories of droughts in 10 Tehsils of Solapur district (Table 2.24) showed that all the Tehsils are chronically drought prone with frequency of all three categories of droughts exceeding 40 per cent. Among the Tehsils, frequency of droughts is highest (60%) in Sangola and lowest (42%) in Barshi and Mangalwedha. In all Tehsils except Karmala and

Mangalwedha, mild droughts are more frequent than other category of droughts. The frequency of severe droughts ranged from 2 to 9 per cent across all tehsils of the districts.

Table 2.24. Meteorological droughts of different intensities in ten Tehsils of Solapur district

Tehsil	Category			
	No drought	Mild drought	Moderate drought	Severe drought
Akkalkot				
No. of years	22	16	5	3
Percent	47	35	11	7
Barshi				
No. of years	26	11	6	2
Percent	58	25	13	4
Karmala				
No. of years	24	9	9	3
Percent	53	20	20	7
Madha				
No. of years	24	12	7	1
Percent	55	27	16	2
Malshiras				
No. of years	19	13	7	1
Percent	45	30	16	9
Mangalwedha				
No. of years	26	6	10	2
Percent	58	14	23	5
Mohol				
No. of years	26	11	7	2
Percent	57	24	15	4
Pandharpur				
No. of years	19	15	7	3
Percent	43	34	16	7
Sangola				
No. of years	17	15	10	1
Percent	40	35	23	2
Solapur				
No. of years	19	16	6	1
Percent	46	38	14	2

THRISSUR

Reference evapotranspiration *versus* pan evaporation

The mean monthly reference evapotranspiration computed using CROPWAT model was compared with the mean monthly pan evaporation (Fig.2.18). The differences in reference and open pan evaporations were found to be higher during December to April and in rest of the months both reference and open pan evaporations were closer. The under-estimation of reference evapotranspiration in winter months (December to April) in Palghat and Thrissur regions can be attributed to strong dry winds blowing from Palakkad gap. By regressing long-term (1984-2010) reference evapotranspiration values against open pan evaporation in each season, pan coefficients for winter and summer seasons were worked out as 0.83 and 0.89, respectively.

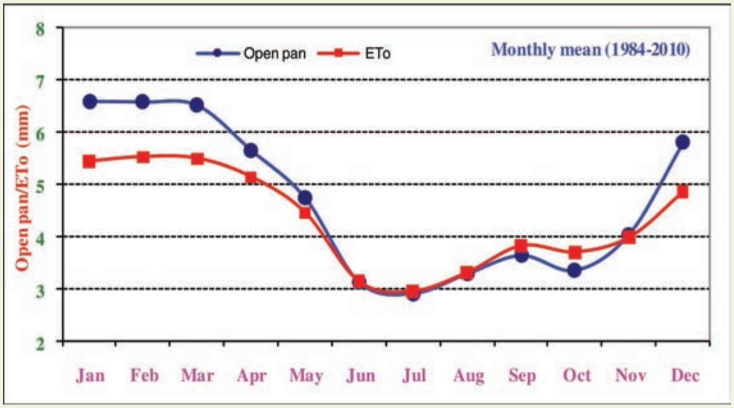


Fig.2.18. Comparison of mean monthly open pan evaporation and reference evapotranspiration in Kerala

UDAIPUR

Seasonal rainfall and rainy days in southeast Rajasthan

Long-term (1970-2008) rainfall and rainy days were analyzed to work out seasonal distribution of rainfall and rainy days in different districts of southeast Rajashtan (Table 2.25). The analysis showed that the maximum annual rainfall (1098.2 mm) and monsoon season rainfall (1041.7 mm) were recorded at Banswara district. Lowest annual (542 mm) and southwest monsoon (496.6 mm) rainfall was recorded in Rajsamand district. Maximum rainy days occured during both southwest monsoon (38) and total year (41) at Banswara and Pratapgarh districts. However, the rainy days during monsoon season and the whole year were lowest (22 and 24 days, respectively) at Sirohi district.

Table 2.25. Mean Seasonal rainfall (mm) and rainy days in different districts of south east Rajasthan

Districts	Southwest monsoon (June-Sep)	Post-monsoon (Oct-Dec)	Winter (Jan-Feb)	Summer (Mar-May)	Annual
Udaipur	550.6(28)	28.9(2)	7.0(1)	15.2(1)	601.7(32)
Rajsamand	496.6(25)	24.8(2)	4.9(0)	15.6(2)	542.0(29)
Chittorgarh	748.2(32)	25.6(2)	8.1(0)	21.1(2)	802.9(36)
Bhilwara	638.6(28)	24.2(1)	9.3(1)	19.6(2)	691.6(32)
Dungarpur	685.6(30)	32.6(2)	4.1(0)	9.6(0)	732.0(32)
Banswara	1041.7(38)	42.3(2)	5.5(0)	8.7(1)	1098.2(41)
Bundi	651.1(28)	26.3(1)	9.2(1)	16.4(2)	702.9(32)
Baran	734.4(32)	49.3(2)	9.0(1)	17.4(1)	810.2(36)
Kota	668.0(30)	34.6(2)	9.3(1)	18.6(1)	730.5(34)
Jhalawar	820.9(33)	43.1(2)	10.3(1)	12.9(1)	887.2(37)
Sirohi	550.2(22)	27.3(1)	3.8(0)	12.6(1)	593.9(24)
Pratapgarh	863.5(38)	47.6(2)	6.2(0)	8.7(1)	926.1(41)

(Figures in parenthesis are rainy days)

Probability of monthly rainfall

Monthly rainfall expected at 90, 75 and 50 per cent probabilities in 12 districts of southeast Rajasthan (Fig. 2.19) showed that highest rainfall at 75 per cent probability level can be expected in the month of July at Banswara, Bhilwara, Bundi, Kota and Pratapgarh districts while it was expected in the month of August at Baran, Chittorgarh, Dungarpur, Jhalwar and Udaipur districts.

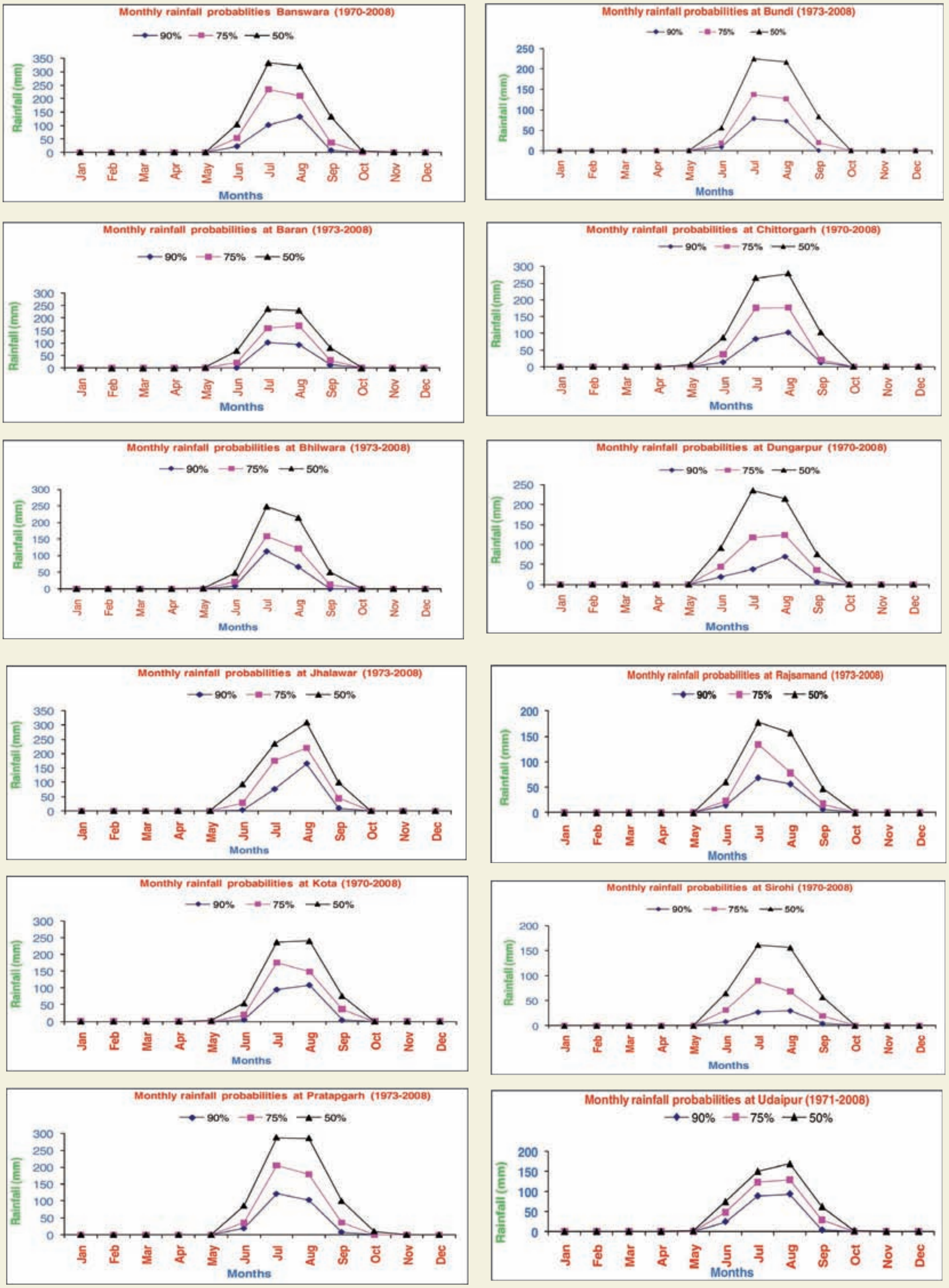


Fig.2.19. Monthly rainfall at different probabilities in districts of southeast Rajasthan

3. CROP-WEATHER RELATIONSHIPS

CHICKPEA

AKOLA

To study crop-weather relations in chickpea, three varieties, *viz*., AKG-46, JAKI-9218 and SAKI-9516 were exposed to three different thermal and moisture regimes by sowing them on 1st, 8th and 15th October 2009.

Influence of weather on yield

Contrary to the results of previous years, higher seed yield were obtained in delayed sowing compared to early sowing conditions because of higher rainfall and soil moisture during pod formation and seed development and lower mean temperatures prevailed during pod formation to seed development stages of 15th October (late) sown crop than under early sown conditions (Table 3.1).

Table 3.1. Yield and yield attributes of chickpea and weather conditions at different phenological stages during 2009 at Akola

Date of sowing	Seed yield (kg/ha)	Stover yield (kg/ha)	Plant height (cm)	Pods/ plant	100 seed weight (g)	Soil moisture (cm^3/cm^3)		Rainfall (mm)		Temperature	
						Pod formation	Seed development	Pod formation	Seed development	Pod formation	Seed development
7th Oct	810	1625	28.0	15.6	19.5	52.4	46.7	0	15	22.1	20.2
8th Oct	906	1650	27.1	17.6	20.3	53.4	47.9	1	26	21.8	19.9
15th Oct	938	1540	25.5	18.9	20.9	53.1	52.2	5	40	21.2	19.8

Effect of temperature on seed yield

Correlation coefficients of seed yield with maximum, minimum and mean temperature during different phenophases of the reproductive period and also the total growing period (Table 3.2) showed significant adverse effect of both maximum and mean temperature during flowering and seed development stages. Minimum temperature showed significant negative effect on yield during pod formation stage as well as the total crop growing period.

Table 3.2. Correlation coefficient between seed yield of chickpea and temperature in different phenological stages at Akola

Parameters	Flowering	Pod formation	Seed development	Total growing period
MaxT	-0.998*	-0.524	-1.000**	-0.693
MinT	-0.858	-1.000*	-0.823	-0.998*
MeanT	-1.000**	-0.880	-1.000**	-0.896

(* = Significant at 0.05 P level ** = Significant at 0.01 P level)

ANANTAPUR

To understand the influence of weather on chickpea, cultivar JG-11 was exposed to three environmental conditions by sowing the crop at three different dates, *viz.*, 5th Nov, 23rd Nov and 10th Dec 2011 and also subjected to three different irrigation treatments (rainfed, irrigation at 35 and 55 days). The yield and yield attributes of chickpea in association with weather parameters (Table 3.3) brought out that low maximum temperature during reproductive period favoured to get higher yield and pods per plant in chickpea.

Table 3.3. Yield and yield attributes of chickpea as influenced by dates of sowing and time of irrigation during 2009-10

Treatments	Number of pods per plant	Test weight (g)	Pod yield (kg/ha)	T_{Max} (°C)		T_{Min} (°C)	
				Vegetative period	Reproductive period	Vegetative period	Reproductive period
Irrigated							
Rainfed	15.0	19.7	1053	—	—	—	—
Irrigation at 35 DAS	20.9	19.7	1133				
Irrigation at 35 & 55 DAS	28.5	20.9	1423				
SEm ±	**1.2**	**0.5**	**50.8**				
C.D at 5%	**3.3**	**NS**	**141.2**				
Date of Sowing							
05.11.2009	25.8	19.9	1329	29.2	29.9	20.5	18.0
23.11.2009	20.4	19.8	1310	29.6	30.5	18.3	17.4
10.12.2009	18.2	20.5	969	29.7	32.2	17.5	18.1
SEm ±	**0.8**	**0.4**	**70.5**				
C.D at 5%	**1.7**	**NS**	**153.7**				

FAIZABAD

Radiation use efficiency (g/MJ) increased with age of the crop till 90 days after sowing and thereafter gradually declined under different treatments (Table 3.4). Chickpea sown on 5th Nov recorded higher RUE at all the stages followed by 21st Oct sowing and lowest in 20th Nov sowing. Different varieties exhibited different radiation use efficiencies (RUE). Higher radiation use efficiency was achieved by Radhey followed by Pusa 362 at all the stages of Chickpea while the lowest RUE was recorded in Uday variety.

Table 3.4. Radiation use efficiency (g/MJ) of Chickpea as affected by various sowing dates and genotypes at Faizabad

Treatment	Days after sowing							
	30	45	60	75	90	105	120	135
Sowing dates								
21st Oct	0.95	1.12	1.18	1.26	1.53	1.42	1.35	1.22
5th Nov	0.99	1.15	1.26	1.28	1.60	1.58	1.40	1.29
20th Nov	0.91	1.09	1.10	1.21	1.46	1.39	1.34	1.21
Varieties								
Radhey	0.93	1.08	1.18	1.24	1.50	1.32	1.27	1.22
Pusa 362	0.96	1.13	1.22	1.27	1.56	1.36	1.28	1.26
Uday	0.92	1.05	1.16	1.22	1.48	1.31	1.24	1.20

JABALPUR

To study the effect of weather on yield and yield attributes, two varieties, JG-315 and JG-11 were exposed to six different thermal and photoperiodic regimes by planting the crop on six dates, *viz.*, 11th Oct, 26th Oct, 10th Nov, 27th Nov, 10th Dec and 25th Dec. 2009.

Effect of temperature on yield

Analysis of seed yield of two varieties of chickpea under six different dates of planting in relation to maximum, minimum and average temperature as well as growing degree days during reproductive period of crop (Fig.3.1) showed that all the three temperatures are bearing highly significant negative relationship with seed yield. However, higher decrease in seed yield with unit increase in minimum temperature (230.4 kg/ha) was observed than with unit increase in maximum (146.6 kg/ha) and average temperature (180.3 kg/ha). The growing degree days during reproductive period, however, showed significant curvilinear relationship with seed yield and growing degree days of 750°C day were found to be optimum for achieving higher seed yield.

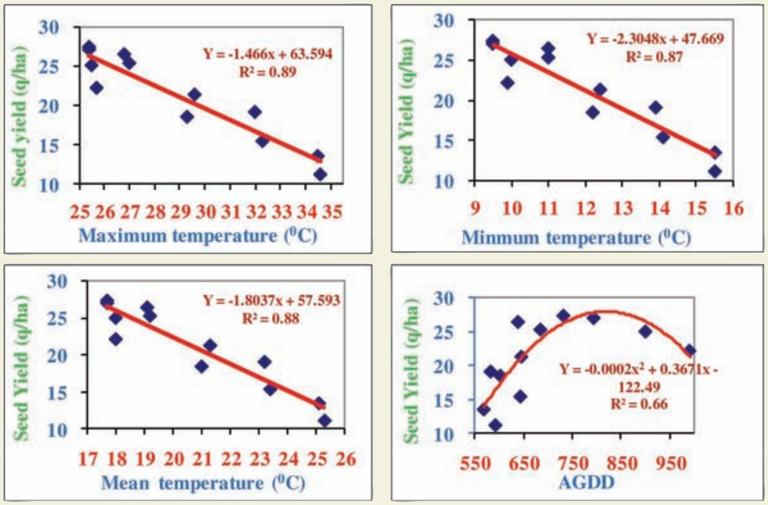


Fig.3.1.Effect of temperature and growing degree days on seed yield of chickpea at Jabalpur

Influence of weather indices on yield and yield attributes

The data on seed yield and other yield attributes along with weather indices, growing degree days (GDD), heliothermal units (HTU) and photothermal units (PTU) during reproductive period of chickpea (Table 3.5) showed that highest seed yield, biological yield and number of filled pods were achieved when per day GDD, HTU (product of GDD and sunshine hours) and PTU (product of GDD and day length) during reproductive period were lowest and *vice versa*. In other words, higher temperature, longer days and more sunshine hours during reproductive period are detrimental to seed yield. Optimum GDD, HTU and PTU identified for obtaining highest yield were 12.3°C day, 90.6°C hr and 142.1°C hr, respectively.

Table 3.5. Yield and yield attributes of chickpea and associated weather indices during reproductive period at Jabalpur

Date of sowing	Seed yield (kg/ha)		Biological yield (kg/ha)		No. of filled pods/10 plant		Reproductive period		
	JG-315	JG-11	JG-315	JG-11	JG-315	JG-11	GDD (°C day)	HTU (°C hr)	PTU (°C hr)
11-10-2009	2220	2510	5180	5370	422	606	12.6	89.8	135.3
26-10-2009	2710	2740	6420	6050	466	677	12.3	90.6	142.1
10-11-1009	2540	2650	6360	6050	374	383	13.9	103.0	153.3
27-11-2009	1850	2140	4140	4570	211	231	15.7	122.9	176.9
10-12-2009	1540	1910	3460	4280	153	209	18.1	162.1	208.4
25-12-2009	1120	1350	2680	3330	112	130	19.5	179.7	229.0

SOLAPUR

To study the effect of weather parameters or indices on yield of chickpea, two cultivars, Vijay and Digvijay were grown under four varied environments by sowing the crop varieties on four dates of sowing, *viz*., 24th Sept, 1st Oct, 18th Oct and 3rd Nov 2009.

Moisture and radiation use efficiency

Moisture use efficiency (MUE), radiation use efficiency (RUE) and yield of two varieties under four dates of sowing (Table 3.6) showed higher MUE and RUE in both the varieties under early sowing (24th Sept) compared to successive late sown conditions. Moisture use efficiency decreased while RUE has not shown any decreasing trend with delay in sowing. The decrease in MUE with each delay in sowing is also reflected in declining yield of chickpea with delay in sowing. The variety Digvijay having higher MUE and RUE under all the dates of sowing maintained its yield superiority over the other variety at all the sowing dates.

Table 3.6. Moisture and radiation use efficiency as well as yield of chickpea varieties under different sowing dates at Solapur

Sowing date	Variety	MUE (kg ha^{-1} mm)	RUE (g MJ^{-1})	Yield (kg/ha)
24-09-2009	Vijay	5.8	2.51	1532
	Digvijay	6.3	2.69	1711
01-10-2009	Vijay	4.1	2.21	1176
	Digvijay	4.5	2.24	1319
18-10-2009	Vijay	3.6	2.41	879
	Digvijay	3.8	2.44	964
3-11-2009	Vijay	2.3	2.31	623
	Digvijay	2.5	2.39	695

Influence of heliothermal units on yield

The yield of varieties Vijay and Digvijay (pooled together) showed highly significant positive relationship with heliothermal units, i.e., the product of degree days and sunshine hours during the total growing period of crop varieties (Fig.3.2). The heliothermal units could explain 96 per cent of yield variability.

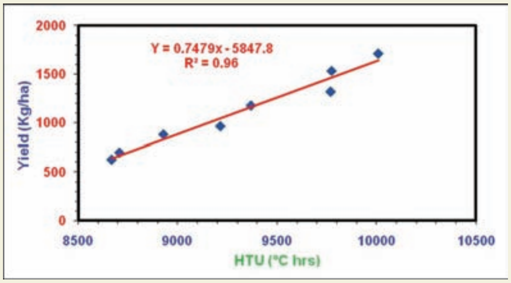


Fig.3.2.Influence of heliothermal units during crop growing period on chickpea at Solapur

WHEAT

KANPUR

To understand the influence of temperature on productivity of wheat, three varieties of wheat (HD-2733, K-307 and K-9107) were exposed to varied thermal regimes by planting the crop on three dates, *viz.*, 30th Nov, 15th Dec and 30th Dec 2009.

Effect of temperature on yield and yield attributes

Correlation coefficients

Correlation coefficients of yield as well as yield attributes of wheat with weather parameters, *viz.*, maximum and minimum temperature, cumulative heat units during vegetative and reproductive periods of the crop and duration of these two stages (Table 3.3) showed that grain yield, straw yield and biomass yield are adversely affected by maximum and minimum temperature during both vegetative and reproductive stages. However, the adverse effects of both maximum and minimum temperature during reproductive stage were more significant than in vegetative stage. Not only yield but also the yield attributes like spikelet per ear, length of the ear, number of grains/ear and 1000 seed weight were adversely influenced by maximum and minimum temperature during the reproductive period. Cumulative heat units during reproductive stage and duration of this stage, however, showed significant positive relationship on yield and most of the yield attributes.

Table 3.7. Correlation coefficients (r) between yield / yield attributes and weather parameters during different phenophases of wheat at Kanpur

Weather parameters	Grain yield (kg/ha)	Straw yield (kg/ha)	Biomass yield (kg/ha)	Harvest index (%)	Spikelet per ear	Length of ear (cm)	No. of grains per ear	1000 seed wt. (g)
Vegetative stage								
T_{Max}	-0.83**	-0.62*	-0.86**	-0.46	-0.35	-0.42	-0.84**	-0.83**
T_{Min}	-0.90**	-0.64*	-0.91**	-0.51*	-0.50*	-0.47	-0.91**	-0.89**
Cum. HU	0.48	0.46	0.57*	0.22	-0.09	0.15	0.48	0.50*
Duration	0.08	0.82**	0.59*	-0.45	-0.06	0.67*	0.17	0.34
Reproductive stage								
T_{Max}	-0.94**	-0.57*	-0.89**	-0.58*	-0.78**	-0.61*	-0.95**	-0.89**
T_{Min}	-0.94**	-0.60*	-0.91**	-0.57*	-0.77**	-0.65*	-0.94**	-0.89**
Cum. HU	0.94**	0.56*	0.88**	0.58*	0.81*	0.61*	0.94**	0.89**
Duration	0.69*	0.87**	0.95**	0.14	0.44	0.80**	0.73**	0.79**

Regression equations developed between grain yield and temperature (maximum and minimum) showed that both maximum and minimum temperature during reproductive period significantly and negatively influenced the yield (Fig.3.3). However, the quantum of reduction in grain yield with unit increase in minimum temperature during reproductive period was higher (445.7 kg/ha) than the reduction with the increase in maximum temperature (238.1 kg/ha).

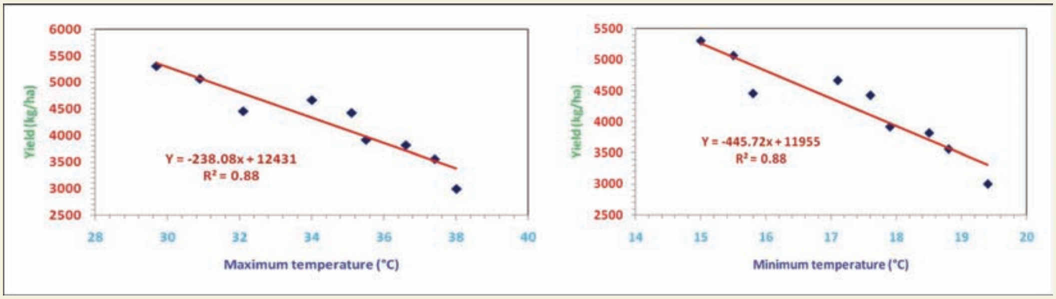


Fig.3.3. Influence of maximum and minimum temperatures on the yield during reproductive stage of wheat at Kanpur

PALAMPUR

The weather parameters that are critical in wheat were identified (Table 3.8). For achieving more than 3 t/ha wheat yield, maximum temperature in the range of 17.8 to 19.9°C with average of 18.6°C and minimum temperature in the range 5.2 to 8.0°C with average of 6.7°C during vegetative phase were identified as critical/optimum temperature limits. Any further rise in the temperature during vegetative stage decreased the yield. Average maximum and minimum temperature of 23.4 and 10.9°C, respectively during reproductive period were found to be optimum for higher yield and any increase or decrease of maximum and minimum temperature over this range decreased the yield.

Table 3.8. Optimum temperature during different phenophases in wheat at Palampur

Temperatures	Vegetative phases	Reproductive phase	Maturity phase
Yield (3.2 t/ha)			
Maximum (°C)	17.8-19.9 (18.6)	20.6-27.1 (23.4)	27.7–31.2 (29.2)
Minimum (°C)	5.2–8.0 (6.7)	8.2–13.3 (10.9)	15.4–18.3 (16.4)
Yield (2 – 3 t/ha)			
Maximum (°C)	17.2–22.1(18.9)	22.2–29.2 (25.9)	27.9–32.7 (30.1)
Minimum (°C)	5.3 – 10.1(7.5)	10.1 – 16.8 (13.8)	15.6 – 19.7 (18.1)
Yield (=2 t/ha)			
Maximum (°C)	19.8–20.2 (20.0)	21.0–22.2 (21.7)	27.9–28.7 (28.4)
Minimum (°C)	7.4–7.9 (7.7)	10.2–10.5 (10.3)	14.9–15.4 (15.2)

RAIPUR

To assess the effect of different thermal conditions on development and yield of wheat and to identify thermal stress tolerant wheat genotypes under late sown conditions, four varieties of wheat, *viz*., Kanchan, GW-273, Sujata and Amar were transplanted on 25th Nov, 5th Dec, 15th Dec, 25th Dec 2009 and 5th Jan 2010.

Heat and radiation use efficiency

Heat and radiation use efficiency of four genotypes under five dates of planting (Table 3.9) showed that both the heat use efficiency (HUE) and radiation use efficiency (RUE) are influenced by varietal differences and varying thermal environments (dates of planting). Averaged over all dates of sowing, Sujata recorded lowest HUE (0.30) and RUE (0.90) followed by Amar, among the varieties. The HUE and RUE averaged over all dates of planting were highest in GW-273 (0.38 and 1.14), closely followed by Kanchan (0.37 and 1.10). All the varieties showed lowest HUE and RUE under the most delayed transplanting on 5th Jan than in early transplanting during 25th Nov to 5th Dec. The varieties Kanchan and GW-273 achieving higher HUE and RUE under all the dates of transplanting compared to the varieties Sujata and Amar are better choice for Raipur region.

Influence of temperature on duration of reproductive stage

The duration of reproductive period in all the four varieties were related with mean maximum, minimum and average temperature during the reproductive period, i.e., 50 per cent flowering to maturity (Fig.3.4). The duration of reproductive period was adversely and significantly affected by maximum, minimum and average temperature during the reproductive period. However, the decrease in duration with unit rise in minimum temperature was higher (2.1 days) than the rise in maximum and average temperature.

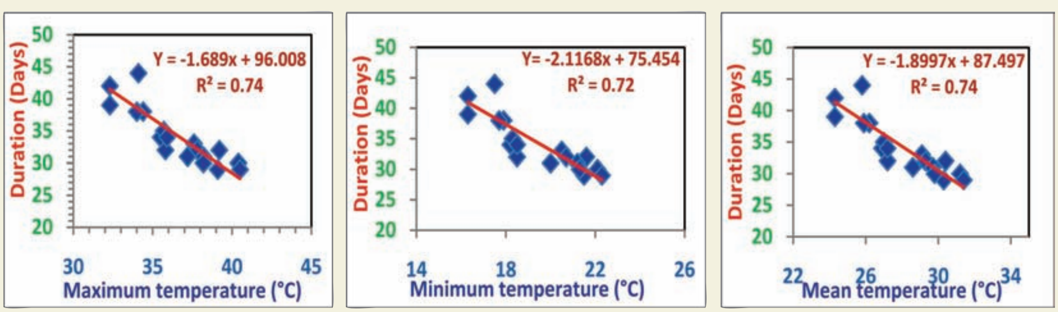


Fig.3.4. Influence of maximum, minimum and average temperature during reproductive stage on wheat yield at Raipur

Table 3.9. Heat and radiation use efficiency of wheat varieties under five sowing dates at Raipur

Variety	Sowing date	HUE ($g/m^2/°C$ day)	RUE ($g/m^2/MJ$)
Kanchan	25 Nov 2009	0.41	1.17
	5th Dec 2009	0.42	1.30
	15th Dec 2009	0.37	1.10
	25th Dec 2009	0.34	1.03
	5th Jan 2010	0.29	0.90
	Mean	**0.37**	**1.10**
GW-273	25 Nov 2009	0.44	1.26
	5th Dec 2009	0.40	1.18
	15th Dec 2009	0.42	1.24
	25th Dec 2009	0.37	1.13
	5th Jan 2010	0.28	0.87
	Mean	**0.38**	**1.14**
Sujata	25 Nov 2009	0.31	0.91
	5th Dec 2009	0.34	1.02
	15th Dec 2009	0.29	0.89
	25th Dec 2009	0.30	0.90
	5th Jan 2010	0.24	0.78
	Mean	**0.30**	**0.90**
Amar	25 Nov 2009	0.33	0.96
	5th Dec 2009	0.31	0.95
	15th Dec 2009	0.33	0.99
	25th Dec 2009	0.33	1.01
	5th Jan 2010	0.24	0.76
	Mean	**0.31**	**0.93**

Thermal Sensitivity Index (TSI)

A thermal sensitivity index (TSI) is the ratio of difference in days taken for maturity of any cultivar in any later planting dates compared to its early sown and the average duration of that cultivar over all the planting dates. It is expressed as:

$$TSI = \frac{\text{Difference in duration}}{\text{Average duration}} \times 100$$

This index was used for assessing thermal stress tolerance of wheat varieties. The cultivars with TSI less than 5, 5.1 to 10, 10.1 to 15 and greater than 15 were categorized as Tolerant (T), Moderately Tolerant (MT), Moderately Sensitive (MS) and Sensitive (S), respectively.

The TSI values of all four genotypes under 10, 20, 30 and 40 days delayed transplanting (Table 3.10) showed that in case of 40 days late transplanting, all the varieties except GW-273 were found susceptible to heat stress. For 10 days delayed transplanting, both Kanchan and GW-273 were tolerant and Sujata and Amar were moderately tolerant. Under 30 days delayed transplanting, only GW-273 was moderately tolerant and rest of the genotypes were either moderately susceptible or susceptible to heat stress.

Table 3.10. TSI values of different wheat genotypes under different transplanting dates

Variety	Delay in transplanting by			
	10 Days	20 Days	30 Days	40 Days
Kanchan	2.9 T	9.8 MT	11.8 MS	16.7 S
GW-273	2.9 T	7.9 MT	9.8 MT	12.8 MS
Sujata	6.5 MT	12.2 MS	16.9 S	18.8 S
Amar	6.5 MT	12.2 MS	16.9 S	18.8 S

Step-wise regression

The influence of different weather parameters on wheat yield were worked out using the step-wise regressions equations presented in Table 3.11. The yield and weather relations revealed that in all the equations, minimum temperature adversely influenced the yield. Though maximum temperature alone showed negative relationship with yield, it showed positive relationship in combination with other weather parameters. The regression equations relating yield with maximum and minimum temperature during reproductive period explaining 71 per cent of yield variation could be the better model for wheat yield prediction in Raipur region.

Table: 3.11. Step-wise regression equations relating wheat yield and weather parameter at Raipur

Regression equations	R^2
$Y = 126.5 - 3.155\ T_{Max}$	0.62**
$Y = 92.73 + 0.28\ T_{Max} - 4.92\ T_{Min}$	0.71**
$Y = 479.5 + 0.29\ T_{Max} - 16.2\ T_{Min} - 2.7\ RH_{I}$	0.77**
$Y = 502.6 + 0.17\ T_{Max} - 16.4\ T_{Min} - 3.16\ RH_{I} + 0.52\ RH_{II}$	0.77**
$Y = 504.0 + 0.17\ T_{Max} - 16.4\ T_{Min} - 3.19\ RH_{I} + 0.59\ RH_{II} - 0.009\ RF$	0.77**

(*Significant at 5% level, ** Significant at 1% level)

RANCHI

To assess the influence of weather parameters on the performance of wheat, three varieties, *viz.*, HUW-468, K-9107 and Birsa Genhu-3 were exposed to three different sets of weather conditions by planting them on three dates, *viz.*, 20th Nov, 5th Dec and 20th Dec 2009.

Water use efficiency

Water use efficiency (WUE) in respect of three varieties of wheat under three dates of sowing (Fig.3.5) showed that all the varieties achieved highest water use efficiency under early sowing (20th Nov) and delay in sowing by 15 days caused reduction in WUE in all the three varieties. Among the varieties, K-9107 recorded lowest WUE under all the three dates of sowing. Interactive effect of varieties and dates of sowing on WUE was also noticed. The variety BG-3 recorded highest WUE under early (20th Nov) sowing while variety HUW-468 recorded highest WUE under normal (5th Dec) sowing.

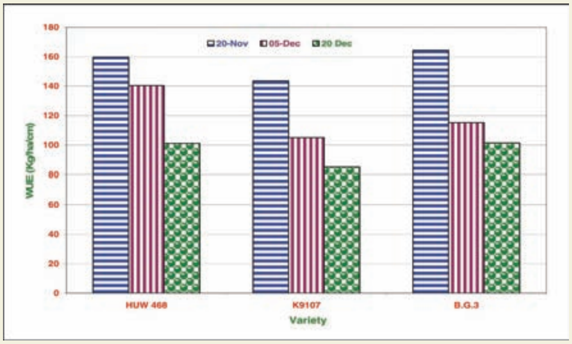


Fig.3.5. Water use efficiency of three wheat varieties as influenced by planting dates at Ranchi

Heat use efficiency (HUE)

Heat use efficiency was also found to be highest under early planting (20th Nov) and *vice versa* (Table 3.12). Among the varieties, HUW-468 achieved highest HUE compared to other two varieties.

Table 3.12. Heat use efficiency of wheat under different planting dates and varieties at Ranchi

Date of planting	HUE (kg/ha/°C)	Variety	HUE (kg/ha/°C)
20-11-2009	3.5	HUW-468	3.4
05-12-2009	2.6	K-9107	2.5
20-12-2009	2.3	BG-3	2.5

Effect of temperature on yield and yield attributes

Yield and yield attributes of wheat varieties under different thermal and moisture regimes (Table 3.13) showed that not only grain yield but also the yield attributes like plant height, grains/spike, 1000 grain weight and total dry matter were reduced with increase in maximum and minimum temperature during reproductive period due to delay in sowing. Low soil moisture during booting to milking stage also contributed for reduction in yield and yield attributes in delayed sowings compared to those in early sown crop.

Table 3.13. Effect of moisture and thermal regimes on yield and yield attributes of wheat at Ranchi

Treatments	Plant ht (cm)	Grain/ spike	1000 grain wt (g)	TDM (g/m^2)	Yield (kg/ha)	Temperature Maximum	Temperature Minimum	Soil moisture (%)
20th Nov	87	45.56	38.5	440.3	**4937**	30.4	12.5	15.8
5th Dec	81.6	41.78	34.3	358.6	4249	34.0	15.2	15.3
20th Dec	75	35.89	32.8	267.2	3535	35.1	16.0	13.8
C D at 5%	**3.41****	**4.60****	**2.05****	**39.33****	**5.26****			
HUW-468	77.67	43.44	33.50	335.2	**4595**	33.2	14.5	
K-9107	91.56	35.56	40.04	360.8	3814	33.2	14.6	
BG.3	74.33	44.22	31.98	370.1	**4352**	33.2	14.5	
S Em	**1.14**	**1.53**	**0.68**	**13.12**	**1.75**			
C D at 5%	**3.41****	**4.60****	**2.05****	**39.33**	**5.26***			

Effect of minimum temperature on yield

Analyzing past four years (including 2009-10) yield data in relation to minimum temperature during reproductive period (Fig.3.6), it was observed that minimum temperature during reproductive period significantly and adversely affected the yield. Unit increase in minimum temperature could reduce the yield by 215 kg/ha.

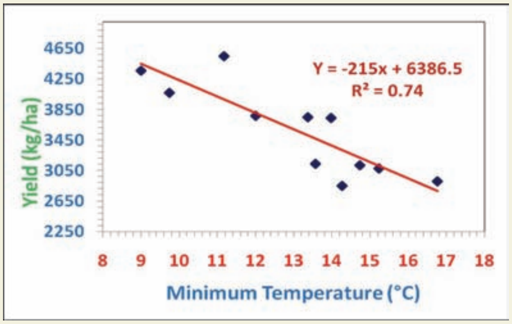


Fig.3.6. Effect of minimum temperature during reproductive period on wheat yield at Ranchi

RANICHAURI

To study the effect of weather on growth and yield of wheat, two varieties, *viz.*, UP-1109 and Sonalika (RR-21) were exposed to three different thermal regimes by sowing the crop on three dates, *viz.*, 30th Oct, 20th Nov and 10th Dec 2009.

Effect of weather on growth parameters

The growth parameters like periodic total drymatter and plant height were related with weather indices, *viz.*, growing degree days and actual evapotranspiration at those periods. The total drymatter could show a significant curvilinear relationship with growing degree days (Fig. 3.7a). However, the plant height showed highly significant positive power relationship with actual evapotranspiration (F.3.7b).

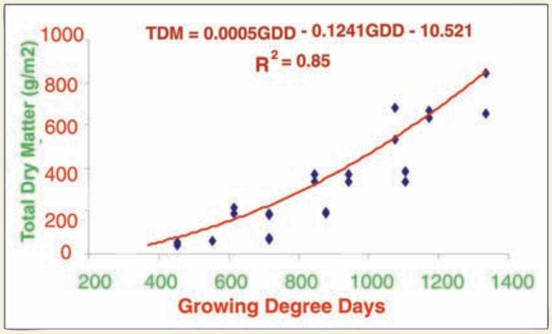


Fig.3.7a. Relationship between total drymatter and growing degree days at Ranichauri

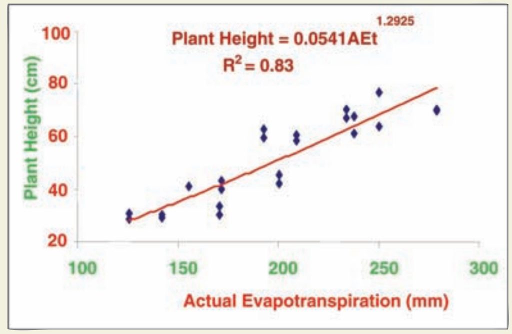


Fig.3.7b. Relationship between plant height and actual evapotranspiration at Ranichauri

RAKH DHIANSAR

Interception of photosynthetically active radiation

Periodic interception of photosynthetically active radiation (PAR) recorded in two varieties of wheat, *viz*., PBW-343 and RSP-561 grown under rainfed and irrigated conditions (Fig. 3.8) revealed that rate of interception of PAR was more under irrigated conditions than under rainfed conditions. Regarding varietal effect on interception, the rate of interception in RSP-561 was observed to be more than in PBW-343 under both rainfed and irrigated conditions.

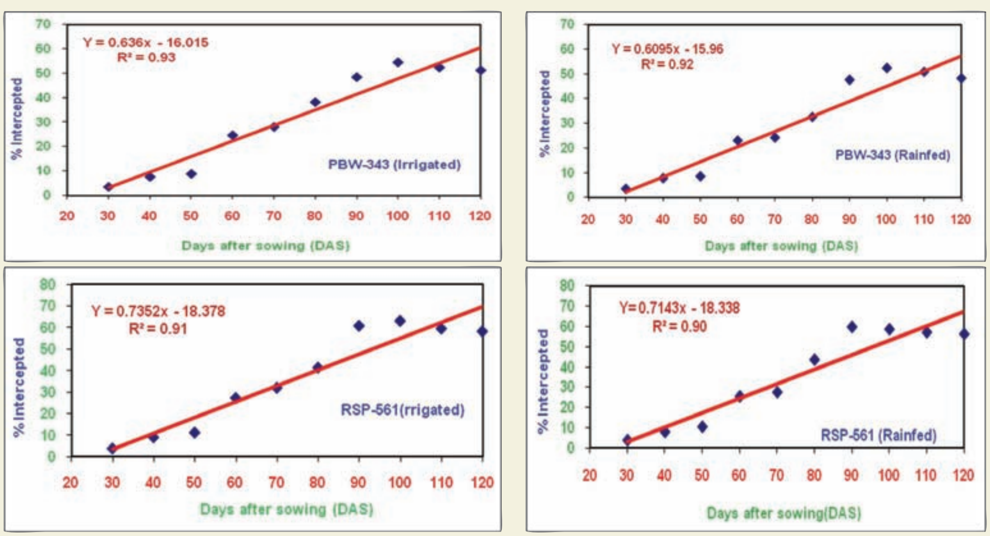


Fig.3.8. Intercepted photosynthetically active radiation (%) in two wheat varieties under irrigated and rainfed conditions at Rakh Dhiansar

SAMASTIPUR

To study the response of varieties, HD-2824, K-307, CBW-38 and HD-2733 under different thermal regimes, these varieties were exposed to varied micro-environments, by sowing them on four staggered planting dates, *viz.*, 25th Nov, 5th Dec, 15th Dec and 25th Dec 2009.

Effect of temperature on phenology

Duration of three phenological stages along with average temperature during these stages (Table 3.14) showed that increase in average temperature during milking to dough stage and 50 per cent flowering to dough stage with successive delay in sowing caused reduction in the duration of these stages. However, increase in temperature during 50 per cent flowering to milking stage by 3°C in late sowing (25th Dec) compared to early sowing (25th Nov) has not affected the duration of that stage. But in milking to dough stage, 2.1°C increase in temperature under late sowing compared to early sowing significantly reduced the duration by 6 days. Increase in temperature by 4.3°C during 50 per cent flowering to dough stage reduced the duration of that stage by 8 days.

Table 3.14. Temperature and duration of different phenophases of wheat at Samastipur

Date of Sowing	Temperature (°C)		
	50 % Flowering to milking stage	Milking to dough stage	50 % Flowering to dough stage
25th Nov	22.0 (8 Days)*	23.9 (27 days)	23.5 (34 days)
05th Dec	22.4 (10 days)	24.8 (25 days)	24.1 (34 days)
15th Dec	22.7 (8 days)	25.3 (24 days)	24.8 (31 days)‘
25th Dec	25.0 (8 days)	26.0 (21 days)	27.8 (26 days)

(Values in parentheses are duration of phenophase)

Effect of temperature on yield

The temperature during milking to dough stage was found to have a parabolic relationship with grain yield of wheat (Fig.3.9). The temperature between 24.5 and 25°C was observed to be optimum for achieving highest yield and increase in temperature beyond this range reduced the yield.

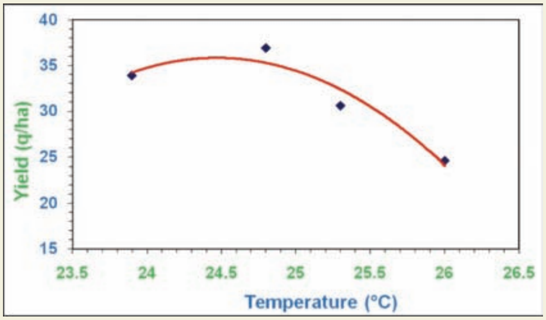


Fig.3.9. Effect of temperature during milking to dough stages on grain yield of wheat at Samastipur

UDAIPUR

To study the effect of weather on growth, development and yield of wheat, variety Raj-3077 was grown under four different micro-environments (sowing dates), *viz*., 5th Nov, 19th Nov, 4th Dec and 19th Dec 2009 and was further subjected to four different levels of irrigation (I_3 to I_6). In I_3 – three irrigations, one each at CRI, late jointing and milking; I_4 – four irrigations, one each at CRI, late jointing, flowering and milking; I_6 – six irrigations, one each at CRI, tillering, late jointing, flowering, milking and dough stages were applied.

Effect of temperature on phenological stages

Emergence stage

The following regression equation relating days taken for emergence of seedlings and mean temperature during sowing to emergence revealed that days taken for emergence (Y) are inversely related to mean temperature (X) and higher the mean temperature, shorter the time taken for emergence and *vice versa*.

$$Y = 11.2 - 0.31 \quad X \quad \ldots (R^2 = 0.74)$$

Vegetative period

Duration of vegetative phase, i.e., the period from sowing to heading of wheat was inversely related with the mean temperature during that period (Fig.3.10). Increase in average temperature during sowing to heading by 1°C resulted in reduction of the duration of vegetative period by about 3.3 days.

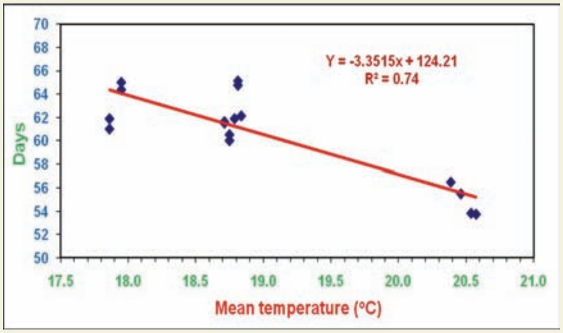


Fig.3.10. Duration of vegetative phase of wheat as influenced by mean temperature at Udaipur

Reproductive period

Duration of reproductive stage, i.e., period from heading to maturity of wheat showed highly significant inverse relationship with average temperature during heading to maturity (Fig. 3.11). The reduction in duration with unit increase in temperature was more (9 days) in case of reproductive period than in case of vegetative period (3 days).

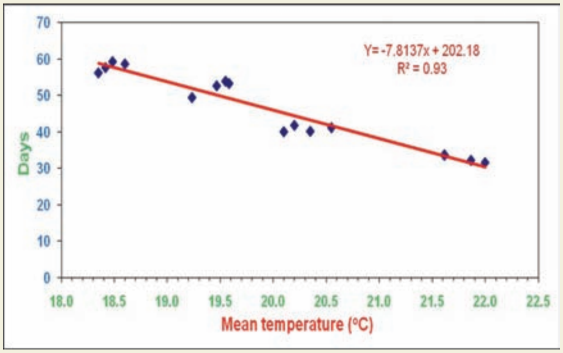


Fig.3.11. Duration of reproductive phase of wheat as influenced by mean temperature at Udaipur

Interception of Photosynthetically Active Radiation (PAR)

The interception of PAR at 90th day in wheat canopy grown on three sowing dates and with four irrigation levels (Table 3.15) showed that percentage of intercepted PAR was highest in normal sown crop (90.7%) and reduced with each delay in sowing under all the three irrigation levels. The irrigation levels, however, increased radiation interception and it was highest in the crop with five irrigations under most of the dates of sowing. The radiation interception was found to be highest (95.7%) in normal sown crop with five irrigations and lowest (71%) in very late sown crop with three irrigations.

Table 3.15. Intercepted PAR (%) at 90 DAS in wheat grown under three dates of planting and irrigation levels at Udaipur

Irrigation levels (No.)	Date of sowing		
	Normal (19th Nov)	Late (4th Dec)	Very late (19th Dec)
3	90.7	84.0	71.0
4	93.7	91.0	84.0
5	95.7	90.7	90.3

Heat use efficiency (HUE)

Heat use efficiency (HUE) with respect to grain yield under four dates of sowing and irrigation levels (Table 3.16) showed that early sown crop registered highest HUE of 3.2 kg/ha/°C and each delay in sowing reduced the HUE significantly and the late sown crop achieved lowest HUE of 1.8 kg/ha/°C. Though, HUE showed increase with increased irrigation levels, the increase is marginal and the crop with 6 irrigations recorded highest HUE (2.9 kg/ha/°C) and with three irrigations recorded lowest HUE (2.5 kg/ha/°C). The results further revealed that the adverse effect high temperature was more pronounced than the positive effect of irrigation on HUE of wheat.

Table 3.16. Heat use efficiency of wheat under different dates of planting and irrigation levels at Udaipur

Date of sowing	HUE (kg/ha/°C)	Irrigation levels (No.)	HUE (kg/ha/°C)
5th Nov	3.2	3	2.5
19th Nov	2.8	4	2.6
4th Dec	2.4	5	2.7
19th Dec	1.8	6	2.9

Effect of temperature on yield

On the basis of three years pooled yield data of wheat grown under different thermal environments (Fig.3.12) it was observed that higher grain yield (4618 to 4665 kg/ha) could be obtained when the mean temperature during reproductive period was around 18.2 to 18.8°C. Increase in temperature during reproductive period by 3.6°C over the optimum temperature limit of 18.2°C caused reduction in yield by 42.2 per cent.

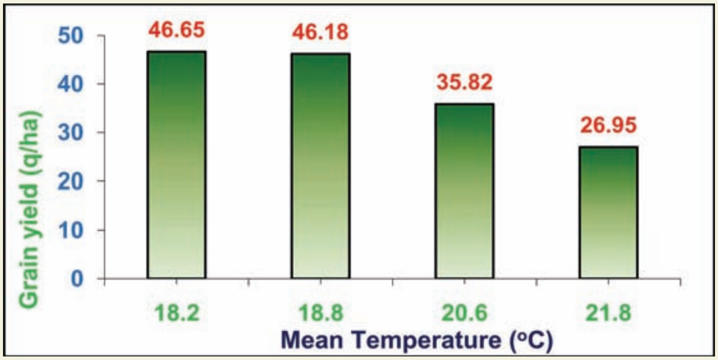


Fig.3.12. Effect of mean temperature during reproductive period on grain yield of wheat at Udaipur

Evapotranspsiration in wheat

Phenological stage-wise evapotranspiration (ET_c) of wheat cv Raj-3077 along with potential evapotranspiration (ET_0) and crop coefficients (Table 3.17) showed that evapotranspiration of wheat cv Raj-3077 during the year 2009-10 was 305.4 mm against open pan evaporation of 338.2 mm. Though the crop coefficient (K_c) was more than one during tillering to dough stage, it was highest in heading stage (1.23). The crop water requirement, however, was found to be highest in milking stage (101.2 mm).

Table 3.17. Pattern of ETc, ETo and Kc during different phenological stages of wheat variety Raj-4037 (2009-10) at Udaipur

Phenological stages	ETc (mm)	ET_0 (mm)	Crop coefficient (Kc)	Duration
Emergence	10.65	14.48	0.74	7
CRI	28.4	32.6	0.87	21
Tillering	20.2	17.1	1.18	30
Heading	80.3	65.4	1.23	65
Milking	101.2	83.0	1.22	94
Dough	85.4	84.2	1.01	113
Maturity	24.3	41.4	0.59	120
Total	**350.4**	**338.2**	**1.04**	**120**

MUSTARD

HISAR

Thermal use efficiency:

The thermal use efficiency (TUE) at various phenophases under different sowing environments was computed and is presented in the Table 3.18. Significantly higher TUE was recorded in the early sown crop as compared to late sown crop, at all phenophases. Among *B. juncea* varieties, Kranti had significantly higher TUE at 50 per cent flowering, 100% flowering and physiological maturity stages followed by Laxmi. Among the genotypes of *B. napus*, HNS- 0004 had significantly higher TUE than other varieties, followed by HNS-0403, at all the stages. The decrease in TUE with delay in sowing was due to the fact that delayed sowing of *Brassica* crop caused forced maturity due to higher temperatures faced by late sown crop during reproductive phase.

Table 3.18. Thermal use efficiency of *Brassica* cultivars at various phenophases under different sowing environments at Hisar

Sowing dates	Thermal use efficiency (g/m²/°C day)		
	50% flowering	100% flowering	Physiological maturity
14th Oct	1.71	1.69	1.67
27th Oct	1.49	1.42	1.33
7th Nov	1.24	1.04	0.96
CD at 5%	**0.03**	**0.04**	**0.02**
Varieties			
GSL1(V_1)	1.69	1.16	1.27
HNS 401 (V_2)	1.44	1.26	1.09
HNS 000 (V_3)	1.72	1.43	1.23
HNS 0403 (V_4)	1.70	1.54	1.35
HNS 0501 (V_5)	1.60	1.35	1.28
RH-30 (V_6)	1.33	1.06	0.96
Laxmi (V_7)	1.57	1.25	1.23
Kranti (V_8)	1.77	1.32	1.27
Varuna (V_9)	1.34	1.12	0.88
RH 819 (V_{10})	1.28	1.02	0.86
CD at 5%	**0.02**	**0.02**	**0.01**

Radiation use efficiency

RUE mainly depends upon three factors, *viz.*, architecture of the canopy intercepting radiation, photosynthetic efficiency of the leaves in utilizing the intercepted radiation used in production of dry matter and loss of dry matter due to physiological causes like respiration. The *Brassica* crop sown on 14th Oct was most efficient in PAR utilization in comparison to crop sown on other two dates (Table 3.19). Though the amount of PAR received above the canopy was almost same in different treatments, the proportion of intercepted PAR differed because of differential crop cover owing to variation in LAI and varying levels of biomass production in different treatments, implying that RUE also differed. Among *B. juncea* varieties, RH30 had higher RUE followed by Kranti at all stages except 100 per cent flowering, whereas both RH-30 and Kranti were at par. Among *B. napus* genotypes, HNS- 0501 efficiently utilized IPAR at all phenophases. The second efficient genotype was HNS- 0401. The highest RUE in the earlier sown crop was due to the maximum PAR absorption and dry matter production, both of which decreased subsequently with the delayed sowing.

Table 3.19. Radiation use efficiency of *Brassica* cultivars at various phenophases under different sowing environments at Hisar

Sowing dates	Radiation use efficiency (g/MJ)		
	50% flowering	100% flowering	Physiological maturity
14th Oct	4.06	4.88	3.95
27th Oct	3.22	3.88	3.16
7th Nov	2.68	2.19	2.79
CD at 5%	**0.07**	**0.12**	**0.05**
Varieties			
GSL1(V_1)	3.50	3.60	3.29
HNS 401 (V_2)	3.77	3.74	3.37
HNS 000 (V_3)	3.18	3.41	3.04
HNS 0403 (V_4)	3.18	3.16	2.72
HNS 0501 (V_5)	3.78	3.74	3.38
RH-30 (V_6)	4.64	4.26	3.92
Laxmi (V_7)	3.72	3.94	3.54
Kranti (V_8)	4.60	4.08	3.85
Varuna (V_9)	2.59	3.81	3.57
RH 819 (V_{10})	4.21	3.87	3.34
CD at 5%	**0.06**	**0.05**	**0.03**

The correlation coefficients determined for seed yield and yield attributes with weather parameters, *viz*., maximum temperature (T_{Max}), minimum temperature (T_{Min}), relative humidity (RH_{Mean}), bright sunshine hours (BSS) and pan evaporation (Ep) are presented in (Table 3.20). The correlation studies revealed that seed yield and yield attributes were significantly and positively correlated with maximum and minimum temperature, sunshine hours and evaporation during vegetative phase but negatively correlated with the same weather parameters at reproductive phase. On the other hand, the relative humidity was found to be significantly and positively correlated with seed yield and yield attributes during reproductive phase and negatively correlated during vegetative phase.

Table 3.20. Correlation coefficients (r) between seed yield / yield attributes and weather parameters during different phenophases in mustard at Hisar

Weather parameters	Phenophases	Seed yield (kg ha^{-1})	Biological yield (kg ha^{-1})	No. of siliquae (m^{-2})	Seeds $siliqua^{-1}$	1000-seed weight (g)
T_{Max}	Vegetative phase	0.80**	0.62**	0.78**	0.34*	0.75**
	Reproductive Phase	-0.82	-0.63	-0.80	-0.34	-0.75
T_{Min}	Vegetative phase	0.36*	0.33*	0.34*	0.38*	0.35*
	Reproductive Phase	-0.82	-0.65	-0.81	-0.35	-0.75
RH_{Mean}	Vegetative phase	-0.80	-0.61	-0.73	-0.38	-0.75
	Reproductive Phase	0.82**	0.62**	0.74**	0.38*	0.73**
BSS	Vegetative phase	0.81**	0.63**	0.82**	0.34**	0.76**
	Reproductive Phase	-0.83	-0.64	-0.80	-0.33	-0.75
Ep	Vegetative phase	0.76**	0.62**	0.72**	0.31*	0.70**
	Reproductive Phase	-0.78	-0.57	-0.82	-0.32	-0.75

(** Significant at (P = 0.01) level of significance; * Significant at (P = 0.05) level)

PALAMPUR

The critical limits in mustard were identified and presented in Table 3.21. For attaining more than 2 t/ha mustard yield a maximum temperature of 18.8°C and minimum temperature of 6.0°C (range 6.0 to 6.1°C) were identified as critical/optimum temperature limits. Any further rise in minimum temperature during reproductive phase decreased the yield due to reduced soil moisture and Aphid attack which resulted into lesser number of pods per plant and consequent lower seed yield (Table 3.21).

Table 3.21. Optimum temperature for different phenophases in mustard crop at Palampur

Temperatures	Vegetative phase	Reproductive phase	Maturity phase
Yield (>2 t/ha)			
Maximum (°C)	20.3 – 24.4 (22.4)	18.7 – 18.8 (18.8)	28.1 – 29.3 (28.7)
Minimum (°C)	7.3 – 9.3 (8.3)	6.0 – 6.1 (6.0)	14.2 – 15.0 (14.6)
Yield (1– 2 t/ha)			
Maximum (°C)	17.0 – 24.4 (19.6)	15.8 – 21.2 (18.2)	22.0 – 29.7 (25.5)
Minimum (°C)	5.3 – 12.1 (7.3)	5.3 – 10.8 (7.8)*	8.9 – 16.6 (13.5)
Yield (<1 t/ha)			
Maximum (°C)	18.9 – 20.9 (19.9)	15.0 – 20.9 (19.3)	22.8 – 24.8 (23.6)
Minimum (°C)	7.0 – 8.1 (7.4)	4.8 – 8.8 (7.6)*	10.9 – 12.5 (11.6)

(*Higher minimum temperature and 13°C mean temperature during reproductive stage has already been identified for aphid attack in mustard.)

UDAIPUR

To study the effect of weather on growth, development and yield of mustard, a variety Bio-902 was exposed to four different micro-environments by sowing on four dates, *viz*., 5th Oct, 20th Oct, 4th Nov and 19th Nov 2010 and four levels of application of irrigation. The four irrigation levels are – No irrigation (I_0), one irrigation at vegetative stage (I_1), two irrigations at vegetative and flowering stages (I_2) and three irrigations at vegetative, flowering and siliquae development (I_3).

Effect of temperature on yield

Like in previous year, seed yield showed positive relationship with maximum, minimum and mean temperature during all the stages at 15 day intervals from sowing to 75th day of crop (Table 3.22). However, from 75th day to maturity, these temperatures adversely affected the yield.

Table 3.22. Correlation coefficient between seed yield and temperatures at different growth stages of mustard during 2009-10 at Udaipur

Temperature	Days after sowing							
	15	30	45	60	75	90	105	106 to maturity
T_{Max}	0.651	0.597	0.631	0.685	0.055	-0.603	-0.628	-0.683
T_{Min}	0.543	0.504	0.415	0.566	0.459	-0.556	-0.689	-0.652
T_{Mean}	0.656	0.629	0.542	0.655	0.291	-0.646	-0.670	-0.678

The plot of seed yield against the mean temperature during 90 to 105 days after sowing (Fig. 3.13) showed that increase of temperature during 90-105 days by 6.1°C in case of late sown crop compared to early sown crop resulted in reduction of yield by 1220 kg.

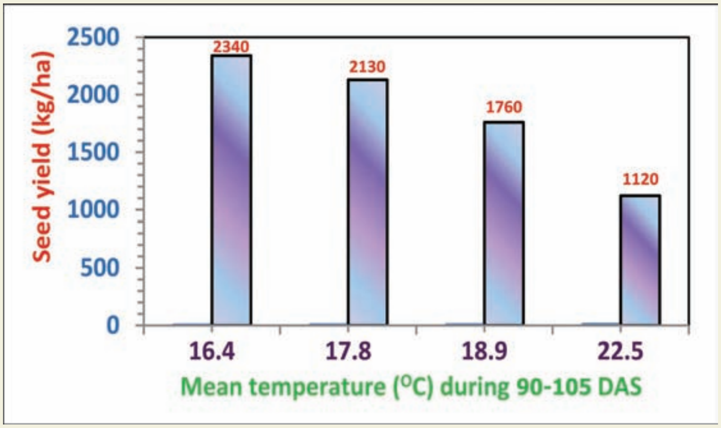


Fig.3.13. Relationship between mean temperature during 90-105 DAS and seed yield of mustard (Mean of 2008-09 and 2009-10)

Rabi SORGHUM

KOVILPATTI

Light interception and light use efficiency (LUE)

A field experiment was conducted during *rabi* to study the light interception and LUE of sorghum based intercropping systems under dryland vertisol conditions. Light interception and LUE under different cropping systems (Table 3.23) indicated that the utilization efficiency was higher under sorghum based intercropping than in sole sorghum. Among the different sorghum based intercropping systems, intercropping system with pulses at 2:1 ratio performed better compared to the system at 4:2 ratio through higher sorghum equivalent yield. Higher interception and utilization of solar radiation was observed under sorghum + cowpea intercropping system followed by sorghum + green gram and sorghum + black gram in different ratios tried. The light interception and utilization was higher in pulses up to 55 DAS (flowering – pod formation stage) after that it decreased. In sorghum light interception and utilization was higher at flowering phase (55-65 DAS).

Table 3.23. Intercepted PAR (%) and its use efficiencies under varied intercropping systems at Kovilpatti

Treat ments	Days after sowing									
	15	25	35	45	55	65	75	85	95	105
I_1*	25(0.21)	38(0.59)	49(0.99)	66(1.56)	81(2.04)	84(2.27)	78(2.15)	71(2.04)	67(1.95)	58(1.88)
I_2	34(0.37)	39(0.74)	60(1.46)	74(1.84)	88(1.92)	62(-)	40(-)	(-)	(-)	(-)
I_3	42(0.31)	54(0.71)	61(1.21)	80(1.96)	85(2.04)	73(-)	49(-)	(-)	(-)	(-)
I_4	56(0.35)	63(1.04)	69(1.57)	84(2.33)	88(2.41)	76(-)	51(-)	(-)	(-)	(-)
I_5	26(0.32)	34(1.08)	51(2.14)	69(2.49)	75(2.56)	58(2.63)	56(2.02)	(-)	(-)	(-)
I_6	39(0.44)	41(1.32)	58(2.36)	70(2.68)	79(2.77)	64(2.41)	61(2.15)	(-)	(-)	(-)
I_7	47(0.51)	54(1.65)	63(2.51)	75(2.91)	82(2.04)	79(2.97)	73(2.33)	(-)	(-)	(-)
I_8	29(0.30)	36(1.18)	54(1.82)	71(2.17)	80(2.22)	62(2.15)	59(1.91)	(-)	(-)	(-)
I_9	43(0.38)	57(1.23)	61(1.95)	74(2.42)	84(2.56)	66(2.48)	63(2.03)	(-)	(-)	(-)
I_{10}	48(0.42)	58(1.45)	69(2.12)	78(2.65)	86(2.79)	81(2.62)	77(2.19)	(-)	(-)	(-)

(Figures in parentheses are percent RUE)

*I_1 - Sole Sorghum
I_2 - Sole Blackgram
I_3 - Sole Greengram
I_4 - Sole Cowpea
I_5 - Sorghum + Blackgram (2:1)
I_6 - Sorghum + Greengram (2:1)
I_7 - Sorghum + Cowpea (2:1)
I_8 - Sorghum + Blackgram (4:2)
I_9 - Sorghum + Greengram (4:2)
I_{10} - Sorghum + Cowpea (4:2)

PARBHANI

To assess the impact of weather conditions on grain and fodder yield of *rabi* sorghum, crop variety SPV-1411 was exposed to four sets of varied weather conditions by cultivating the crop under four dates of sowing, *viz.*, 14^{th} Sept, 28^{th} Sept, 12^{th} Oct and 26^{th} Oct 2009, respectively. This experiment of crop-weather relations in *rabi* sorghum is being conducted for the past 13 years since 1995-96. Pooled analysis of grain and fodder yield data over the years in relation to phenological stage-wise weather parameters (Table 3.24) revealed that rainfall, minimum temperature and relative humidity (morning, afternoon and mean) during boot stage are positively and significantly related to grain yield. The fodder yield is also positively influenced by weather parameters during boot stage. Rainfall, rainy days, temperature (maximum, minimum and mean) and relative humidity (afternoon and mean) positively and significantly influenced the fodder yield of *rabi* sorghum. Relative humidity during boot to maturity influenced both grain and fodder yield, positively and significantly.

Table 3.24. Correlation coefficients between weather variables and grain and fodder yield of *rabi* sorghum at Parbhani

Weather variables	Yield (kg/ha)											
	Boot stage		Flowering stage		Milk stage		Dough stage		Maturity		Booting to maturity	
	Grain	Fodder	Grain	Fodder	Grain	Fodder	Grain	Fodder	Grain	Fodder	Grain	Fodder
RF	0.26*	0.39**	-0.12	0.01	-0.21	0.03	-0.23	-0.18	-0.01	-0.03	0.08	0.15**
RD	0.22	0.36**	-0.13	-0.00	-0.22	-0.02	-0.19	-0.12	-0.02	-0.05	-0.01	0.11
T_{Max}	0.10	0.34**	-0.06	0.19	-0.05	0.16	-0.02	0.06	-0.21	-0.15	-0.05	0.11
T_{Min}	0.25*	0.33**	-0.13	0.08	-0.16	0.03	-0.19	-0.08	-0.16	-0.28*	-0.05	0.05
T_{Mean}	0.22	0.37**	-0.09	0.25*	-0.09	0.22	-0.17	-0.06	-0.17	-0.24*	-0.06	0.15**
RHI	0.29**	0.17	0.36**	0.24	0.08	0.04	0.14	0.06	0.15	0.23	0.20**	0.15**
RHII	0.28*	0.41**	0.26**	0.40**	0.13	0.19	-0.11	0.08	-0.03	-0.07	0.12*	0.21**
RHmean	0.34**	0.36**	0.38**	0.39**	0.12	0.15	0.04	0.10	0.08	0.11	0.19**	0.22**

(* Significant at 5 % level ** Significant at 1 % level)

RF = Rainfall; RD = Rainy days, T_{Max}, T_{Min} and T_{Mean} are maximum, minimum and mean temperature, respectively
RHI, RHII and RH_{Mean} are morning, afternoon and mean relative humidity, respectively

SOLAPUR

To understand the influence of weather on yield of *rabi* sorghum, three varieties, *viz*., M 35-1, Mauli and Vasudha were exposed to four different weather conditions by sowing the crop varieties on 11th Sept, 22nd Sept, 1st Oct and 17th Oct 2009.

Radiation and moisture use efficiency

Perusal of radiation use efficiency (RUE), moisture use efficiency (MUE) and yield of three varieties under four dates of sowing (Table 3.25) showed that highest radiation and moisture use efficiency in all three varieties were achieved in 1st Oct sowing compared to either early or late sowing. Lowest MUE in all the varieties was recorded under early sowing (11th Sept) condition while lowest RUE was observed in late sown (17th Oct) conditions. Among the varieties, Mauli achieved lowest RUE at each date of sowing and its yield was also lowest among the varieties under each date of sowing. The higher RUE and MUE achieved in all three varieties sown on 1st Oct was also reflected in yield achieved by varieties in case of 1st Oct sowing compared to other sowing dates.

Table 3.25. Radiation and moisture use efficiency and grain yield of three varieties and four sowing dates at Solapur

Sowing date	Variety	MUE (kg ha^{-1} mm)	RUE (g MJ^{-1})	Yield (kg/ha)
11-09-2009	M 35-1	1.1	3.13	345
	Mauli	0.9	2.86	265
	Vasudha	0.9	3.01	316
22-09-2009	M 35-1	3.3	3.17	1010
	Mauli	2.9	2.83	770
	Vasudha	3.0	2.92	978
01-10-2009	M 35-1	4.7	3.28	1324
	Mauli	4.4	3.08	1085
	Vasudha	4.2	3.21	1224
17-10-2009	M 35-1	3.6	2.90	978
	Mauli	2.7	2.77	640
	Vasudha	2.9	2.87	824

Yield as influenced by consumptive use of moisture

The consumptive use of moisture (CU) during the total growing period of *rabi* sorghum (Fig.3.14) showed a curvilinear relationship with grain yield. The CU of 270 mm was found to be optimum for obtaining higher yield and increase in CU beyond this optimum limit reduced the yield.

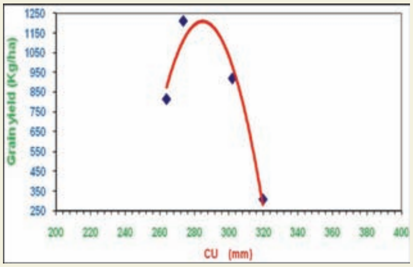


Fig.3.14. Relation between grain yield and CU in sorghum at Solapur

SUNFLOWER

BIJAPUR

Data collected from five years of experimentation with four varieties, *viz*., KBSH-1, Ganga Kavery- 2002, Sunbreed-275 and NSP 92-1(E) and three dates of sowing were analyzed through statistical methods, and the correlation analysis was performed between meteorological variables prevailing during individual phenological stages and grain yield of sunflower crop. Regression models were developed between yield and weather parameters during different phenological stages (Table 3.26).

Table 3.26. Regression models relating yield and weather parameters at Bijapur

Physiological stage	Models	R^2
Seedling (S)	Y = 139.0 VP2(S) - 829.6	0.39
Vegetative (V)	Y = 90.1 VP2(V) - 768.7	0.45
S & V	Y = 14.5 VP2(V) + 72.7 RH2 (S) - 1382.8	0.53
V & Flowering (F)	Y = 55.7 VP2(V) + 74.3 CC2(F) - 737.3	0.56
S, V & F	Y = 5.9 VP2(V) + 43.0 CC2(F) + 70.8 RH2 (S) - 995.2	0.57

Where:
VP2 = Afternoon vapour pressure in mm Hg.
RH2 = Afternoon relative humidity in per cent.
CC2 = Afternoon cloud cover in Octa.
The alphabets in the parenthesis indicate the stage of the crop

Sunflower yield forecast can be made in seedling stage by using the afternoon vapour pressure as the dependent variable with accuracy of 39 per cent and at vegetative stage the same variable gives 45 per cent accuracy. By considering the hygric factors in both seedling and vegetative stages, the accuracy level could be increased to 53 per cent. Inclusion of variables from later stages increased the forecast accuracy only by three to four per cent. In order to ascertain the role of weather variables in cases of extreme events, sunflower seed yield, the temporal profiles of temperature and vapour pressure during different crop growth stages are compared with yields that ranged from 274 kg/ha to 1537 kg/ha in the five years of experimentation. It is inferred from the analysis that:

- Increase in vapour pressure above 18 mm of Hg during vegetative stage increases sunflower yield.
- Decrease in vapour pressure below 16 mm of Hg during vegetative stage and below 14 mm of Hg during flowering is unfavourable.
- Decrease in minimum temperature below 16°C during flowering stage is unfavourable for crop yields.

MANGO

DAPOLI

Analysis of 13-year data on the number of days taken for the occurrence of different phenophases in Alphonso Mango in relation to concurrent weather parameters resulted in development of functional relations that could be used to predict the initiation of phenophases like vegetative flush, reproductive flush and harvest of the crop. The resultant relations thus obtained are presented in Table 3.27.

Table 3.27. Multiple regression equations for vegetative, reproductive flush and harvest of mango at Dapoli

Equation	R^2
Vegetative Flush	
$Y=-124.19+0.40(T_{Max}) - 1.711(T_{Min})+2.00(RH\text{-}I)-0.49(BSS)-0.03(Rain)$	0.91*
$Y=-115.22-1.75(T_{Min}) +2.03(RH\text{-}I)-0.324(BSS)-0.032(Rain)$	0.91*
$Y=-135.322-1.69(T_{Min}) +2.21 (RH\text{-}I)-0.03(Rain)$	0.91*
Y=62.368-1.10(Tmin) - 0.023(Rain)	0.69*
Y=40.057-0.031(Rain)	0.52*
Reproductive Flush	
Y=16.11+1.68 (Tmax)-1.01(Tmin)+0.01 (RH-I)-0.90 (BSS)-0.06 (Rain)	0.99*
Y=17.30+1.67 (Tmax)-1.01(Tmin)-0.92 (BSS)-0.06 (Rain)	0.99*
Y=-4.78+2.04 (Tmax)-0.78 (Tmin)-0.04 (Rain)	0.98*
Y=-32.05+2.91 (Tmax)-0.80 (Tmini)	0.95*
Y=67.43-1.29 (Tmin)	0.78*
Harvest	
Y=-48.09+0.74 (Tmax)+0.83 (Tmin)+0.17 (RH-I)+0.95 (BSS)	0.73*
Y=-25.75+0.64 (Tmax)+0.77 (Tmin)+0.66 (BSS)	0.69*

- It is further inferred from the analysis that the post-monsoon shower (39^{th} to 40^{th} SMW) is the most important factor for initiation of vegetative flush of Alphonso mango.
- The minimum temperature (48^{th} to 50^{th} SMW) is important factor for initiation of reproductive flush of Alphonso mango. During this period, the diurnal range of temperature is 12 to 15°C.

POTATO

JORHAT

To quantify the effect of weather condition on tuber yield of potato, three varieties, *viz*., Kufri Megha, Kufri Giriraj and Kufri Jyoti were grown under three varying environments that were created through three different planting dates, i.e., 3rd Nov, 16th Nov and 1st Dec 2009. The following regression equations relating accumulated agroclimatic indices, i.e., accumulated growing degree days (AGDD), accumulated photothermal units (APTU), accumulated bright sunshine hours (ABSH) and accumulated mean temperature (AMET) during tuber formation stage were developed to predict the tuber yield.

Y = 211.4 – 0.13 AGDD ($R^2 = 0.59$)
Y = 212.5 – 0.01 APTU ($R^2 = 0.59$)
Y = 205.1 – 0.16 ABSH ($R^2 = 0.53$)
Y = 202.1 – 0.06 AMET ($R^2 = 0.58$)

MOHANPUR

Yield- Seasonal evapotranspiration (SET) relationship:

A linear relationship was worked out between SET and tuber yield (Fig. 3.15). Tuber yield increased with increase in ET value. Tuber yield increased by 0.383 t/ha with increase in one mm of ET value. From the relationship it is clear that 83 per cent of tuber yield can be predicted by SET value alone.

Y= 0.3831 SET – 27.546 ($R^2 = 0.83$)

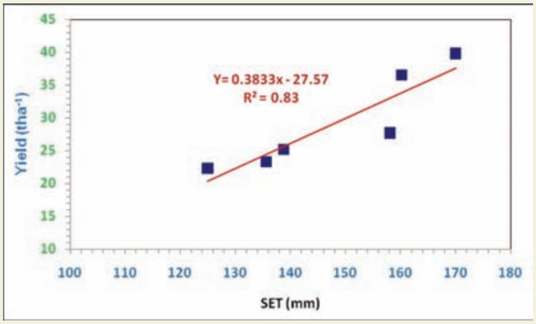


Fig.3.15. Relationship between yield of potato and seasonal evapotranspiration (SET) at Mohanpur

MAIZE

KOVILPATTI

The variations in leaf area index and dry matter production of maize crop showed that the leaf area index and dry matter production was higher in D_4 (42nd standard week) at all phenological stages but was comparable with other three dates. Among the different sowing windows, the crop sown during the pre-monsoon period (39th SMW) recorded higher AGDD followed by other dates of sowing. The higher GDD was registered in the early growth phase and it was decreasing up to silking stage. Thereafter it increased again up to maturity (Table 3.28).

Table 3.28. Influence of sowing dates on the phenology and GDD of maize under rainfed vertisol condition at Kovilpatti

Date of sowing	Stage								
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	AGDD
D_1 - 39th SMW	890	202	191	253	91	206	100	282	2215
D_2 - 40th SMW	745	202	191	253	91	206	100	282	2070
D_3 - 41st SMW	621	202	191	253	91	206	100	282	1945
D_4 - 42nd SMW	481	202	191	253	91	206	100	282	1806

P_1 – Germination; P_2 - Early vegetative phase P_3 - Vegetative phase
P_4 - Flowering phase P_5 - Silking P_6 - Cob formation phase
P_7 - Milking phase P_8 – Maturation

With respect to different plant spacings under rainfed condition, spacing of 60 x15 cm (S_3) performed better. Optimum weather parameters like maximum temperature in 21.8-29.3°C range, minimum temperature of 17.7-23.3°C, RH of 84 – 95 per cent and well distributed rainfall and pan evaporation in the range of 2.9 - 4.8 mm were found to favour the crop growing environment during the *rabi* season.

TEA

PALAMPUR

Effect of seasonal rainfall on tea productivity

The tea productivity for the last 15 years when compared with rainfall of current and previous month showed that the tea yield of April and June was found to be significantly correlated with the rainfall of March and May at two locations, *viz*., Wah Tea Estate and the Tea Husbandry Farm (Table 3.29). During 2006 season at Wah Tea Estate, the yield of same month was found to be significantly correlated with rainfall and temperature of the previous month. The correlation coefficients were not significant during past four seasons 2007 to 2010 (Fig.3.16 & Table 3.30).

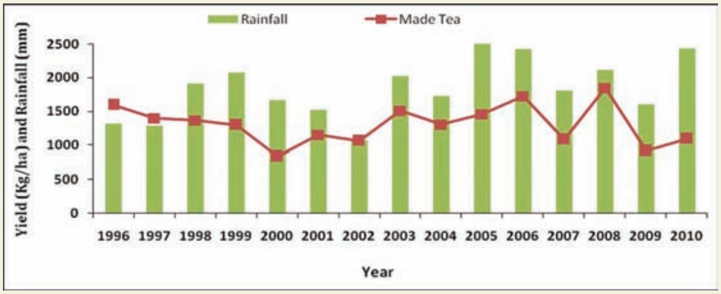


Fig. 3.16. Relation between rainfall and made tea at Palampur

Table 3.29. Correlation coefficient of rainfall and green tea leaves yield in three selected Tea Estates of Palam Valley

Season/Yield and rainfall	Palampur Tea Estate						Banuri Tea Estate						Wah Tea Estate					
	2005	2006	2007	2008	2009	2010	2005	2006	2007	2008	2009	2010	2005	2006	2007	2008	2009	2010
Previous month	0.029	0.191	0.447	0.470	0.485	0.372	0.103	0.536	0.216	0.146	0.186	0.086	0.473	0.826*	0.471	0.473	0.406	0.307
Same month	0.352	0.347	0.501	0.517	0.521	0.413	0.241	0.439	-0.124	-0.162	-0.126	-0.206	0.742*	0.703*	0.437	0.439	0.459	0.352

Table 3.30. Correlation coefficient of mean temperature and green tea leaves yield in three selected Tea Estates of Palam Valley during three seasons

Season/Yield & temperature	Palampur Tea Estate						Banuri Tea Estate						Wah Tea Estate					
	2005	2006	2007	2008	2009	2010	2005	2006	2007	2008	2009	2010	2005	2006	2007	2008	2009	2010
Previous month	0.224	0.030	-0.141	0.490	0.399	0.059	0.106	0.192	0.338	0.540	0.061	0.186	0.551	0.590	0.338	0.862*	0.568	0.475
Same month	0.270	0.050	0.414	0.490	0.259	0.009	0.143	0.465	0.569	0.509	0.142	-0.015	0.277	0.476	0.570	0.575	0.289	-0.054

(*Value of r (0.5) at n-2 = 0.707)

For obtaining higher production of tea leaves, maximum and minimum temperature must not be lower than 16.8 and 6.1°C and any temperature below this limit will reduce the tea leaves production. In order to obtain highest production of tea leaves, the maximum and minimum temperature must not exceed 26.6 and 15.5°C during April, 30.1 and 18.5°C during May, 26.7 and 19.1 during June, 27.9 and 19.7°C during August and 26.4 and 17.7°C during September. The fall of maximum and minimum temperature below 24.2 and 13.5°C during October reduced the tea production drastically (Fig.3.17).

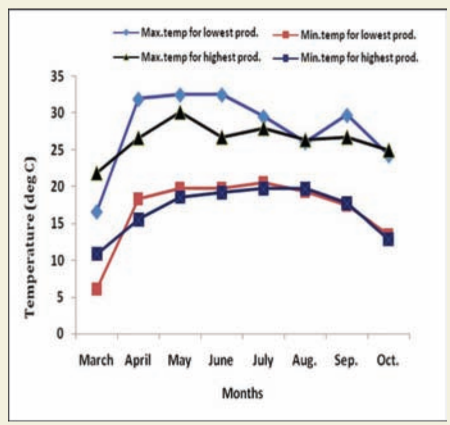


Fig.3.17. Critical temperature for tea leaves production at University tea garden, Palampur

COCONUT

THRISSUR

Effect of weather on leaf shedding

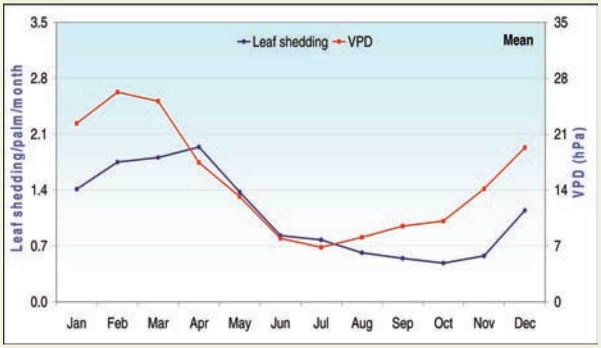


Fig.3.18. Mean monthly vapor pressure deficit versus leaf shedding in coconut at Thrissur

Leaf shedding over the past 7 years including the year 2009-10 was analyzed in relation to ambient temperature, soil moisture deficit and vapour pressure deficit. Out of all these parameters, vapour pressure deficit influenced the yield and pattern of leaf shedding in various months closely followed the trend in vapour pressure deficit (Fig.3.18). The leaf shedding was observed to be highest in January to April months with higher vapour pressure deficit or atmospheric dryness. Lag in leaf shedding of two months in relation to vapour pressure deficit was noticed as the peak leaf shedding occurred in April, two months after the peak vapour pressure deficit in February.

Effect of weather on button shedding

Lower button shedding in June to November was observed due to high soil moisture and lower vapour pressure deficit during that period (Fig.3.19).

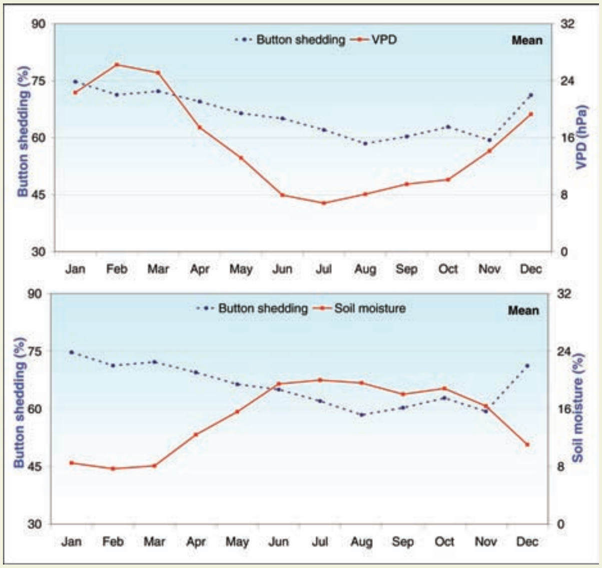


Fig.3.19. Soil moisture and vapour pressure deficit versus button shedding at Thrissur

4. CROP GROWTH MODELLING

CHCIKPEA

AKOLA

Growing degree days

Degree days requirement of three varieties of chickpea, *viz*., AKG-46, JAKI-9218 and SAKI-9516 under three dates of sowing on 1st Oct, 8th Oct and 15th Oct 2009 (Table 4.1) showed decrease in requirement of accumulated growing degree days to reach different phenological stages with delay in sowing. Among the cultivars, highest growing degree days were required by SAKI-9516 (1961°C day) and lowest in AKG-46 (1839°C) day).

Table 4.1. Mean duration of phenological stages (days) of chickpea cultivars under different sowing dates at Akola

Phenophase	V_1- AKG-46	V_2- JAKI-9218	V_3-SAKI-9516	Mean
D_1- 40 SMW (01.10.2009)				
Vegetative stage	911	954	954	940
Flowering	244	248	248	246
Pod formation	279	287	322	296
Seed development	300	317	324	314
Maturity	182	153	180	172
Total	**1916**	**1958**	**2028**	**1967**
D_2- 41 SMW(08.10.2009)				
Vegetative stage	887	902	916	902
Flowering	228	229	268	242
Pod formation	266	296	284	282
Seed development	277	296	301	291
Maturity	154	172	172	166
Total	**1839**	**1876**	**1950**	**1888**
D_3- 42 SMW(15.10.2009)				
Vegetative stage	811	737	862	803
Flowering	243	255	280	259
Pod formation	266	278	282	275
Seed development	287	298	294	293
Maturity	155	175	189	173
Total	**1761**	**1743**	**1906**	**1803**
Mean	**1839**	**1859**	**1961**	

JABALPUR

Days taken and accumulated growing degree days (GDD) required for occurrence of important phenological stages in respect of varieties, JG-315 and JG-11 under six dates of sowing, *viz*., 11th Oct, 26th Oct, 10th Nov, 27th Nov, 10th Dec and 25th Dec 2009 (Table 4.2) revealed that the earliest sown crop took highest number of days for both physiological and harvest maturity (131 and 145 days). With delay in sowing the duration from sowing to physiological maturity or harvest gets curtailed to have shortest durations (92 and 103 days) in late sown crop (25th Dec). Regarding degree day requirement, it was also highest for all phenological stages in early sown crop compared to late sown conditions. The degree days requirement, however, decreased with delay in sowing till 27th Nov only and later it was not showing any increasing or decreasing trend.

Table 4.2. Number of days taken and growing degree days required for occurrence of important phenological stages in chickpea during 2009 at Jabalpur

Date of sowing	50% Flowering		50% Pod initiation		Physiological maturity		Harvest	
	Days	GDD	Days	GDD	Days	GDD	Days	GDD
11th Oct	57	913	76	1179	131	1846	145	2073
26th Oct	60	877	85	1132	121	1630	131	1808
10th Nov	64	806	85	1048	111	1458	117	1573
27th Nov	62	712	80	986	101	1326	118	1684
10th Dec	68	828	78	985	101	1424	115	1765
25th Dec	63	784	73	956	92	1350	103	1632

SOLAPUR

Growing degree days

The cumulative growing degree days required for occurrence of five important phenological stages in two crop cultivars under four sowing dates (Table 4.3) showed that both the varieties sown early (24th Sept) required higher number of degree days (1389 and 1467°C day) at all the stages than under delayed sowing (1132 and 1195°C day). The degree days requirement of variety Digvijay was slightly higher than Vijay under all the dates of sowing.

Table 4.3. GDD required for phenological stages in different sowing dates of chickpea at Solapur

Sowing date	Phenological stage				
	Emergence	Branching	50 % Flowering	Pod formation	Pod maturity
S_1V_1	133	588	915	1097	1389
S_1V_2	152	635	974	1152	1467
S_2V_1	129	571	863	1030	1312
S_2V_2	148	611	918	1091	1381
S_3V_1	117	506	784	939	1216
S_3V_2	135	532	817	979	1260
S_4V_1	109	472	724	869	1132
S_4V_2	127	505	772	925	1195

S_1, S_2, S_3 and S_4 are sowing dates (24th Sept, 1st Oct, 18th Oct and 3rd Nov) and V_1 and V_2 are varieties (Vijyay and Digvijyay)

WHEAT

KANPUR

Harvest Index

Harvest index, an important component in crop simulation modelling was worked out in respect of three genotypes, HD-2733, K-307 and K-9107 under three dates of planting. The harvest index data (Table 4.4) showed that it is not varying much (33.4 to 36.9% only) across different sowing dates. However, it is varying much across the genotypes from 30.6 per cent in K-9107 to 38.1 per cent in HD 2733.

Table 4.4. Effect of sowing dates and varieties on harvest index (%) of wheat at Kanpur

Sowing date	HD-2733	K-307	K-9107	Mean
30th Nov 2009	39.4	39.3	32.1	36.9
15th Dec 2009	38.0	37.0	31.8	35.6
30th Dec 2009	36.8	35.3	28.0	33.4
Mean	**38.1**	**37.2**	**30.6**	—
	Date of sowing (D)	**Variety (V)**	**D x V**	
SE(d)±	0.22	0.35	0.60	
CD at 5%	0.54	0.74	1.31	

RAIPUR

Growing degree days, photothermal units and heliothermal units

Accumulated growing degree days from sowing to occurrence of different phenological stages in respect of four genotypes, Kanchan, GW-273, Sujata and Amar under five sowing dates 25th Nov, 5th Dec, 15th Dec, 25th Dec 2009 and 5th Jan 2010 (Table 4.5) showed that GDD requirement for occurrence of different phenological stages (except CRI and tillering) has not followed any decreasing or increasing pattern with delay in planting, as observed in previous years. The growing degree days for CRI and tillering stages in all the genotypes decreased with delay in sowing. Growing degree days from sowing to maturity of Kanchan and GW-273 were lowest (1728°C day) in 15th Dec sowing and GDD of Sujata and Amar was lowest (1857°C day) in 25th Dec sown crop. Highest GDD for maturity of all the varieties except Kanchan was recorded in case of 5th Jan sowing.

Table 4.5. Accumulated growing degree days (GDD) at different growth stages of wheat varieties under different thermal environments at Raipur

Sowing date	Emergence	C.R.I.	Tillering	Ear emergence	50% Flowering	Milking	Dough	Maturity
Kanchan								
25 Nov 2009	70	346	511	752	974	1341	1568	1792
05 Dec 2009	84	342	498	749	1009	1335	1605	1898
15 Dec 2009	95	293	465	662	975	1302	1601	1728
25 Dec 2009	87	281	434	676	1000	1290	1612	1802
05 Jan 2010	95	258	415	731	1069	1345	1668	1802
GW-273								
25 Nov 2009	70	346	511	738	989	1341	1568	1747
05 Dec 2009	84	342	486	720	973	1335	1605	1771
15 Dec 2009	95	293	465	677	1011	1302	1601	1728
25 Dec 2009	87	281	434	676	1021	1290	1612	1802
05 Jan 2010	95	258	415	731	1045	1345	1695	1858
Sujata								
25 Nov 2009	70	346	528	918	1062	1439	1705	1987
05 Dec 2009	84	342	498	920	1144	1472	1649	1926
15 Dec 2009	79	293	478	897	1127	1415	1675	1867
25 Dec 2009	87	281	448	924	1087	1335	1722	1857
05 Jan 2010	80	258	430	976	1155	1395	1775	1943
Amar								
25 Nov 2009	70	346	544	932	1062	1439	1705	1987
05 Dec 2009	84	342	511	920	1162	1472	1649	1926
15 Dec 2009	79	293	478	919	1127	1415	1675	1867
25 Dec 2009	87	295	461	962	1111	1335	1722	1857
05 Jan 2010	80	271	442	998	1178	1395	1775	1943

The photothermal units and heliothermal units of all the varieties from sowing to maturity were highest in 5th Jan planting (Table 4.6). The GDD, PTU and HTU under all the sowing dates were highest in Sujata and Amar compared to Kanchan and GW-273 due to their longer duration.

Table 4.6. Accumulated Photothermal Units and Heliothermal Units from sowing to maturity of wheat varieties grown under different thermal environments at Raipur

Sowing date	Maturity	
	Photothermal Units(^{0} C hr)	Heliothermal Units(^{0} C hr)
Kanchan		
25 Nov 2009	19806	14464
05 Dec 2009	20276	14862
15 Dec 2009	19386	14369
25 Dec 2009	20476	15306
05 Jan 2010	20755	15694
GW-273		
25 Nov 2009	19270	14040
05 Dec 2009	19698	14383
15 Dec 2009	19386	14369
25 Dec 2009	20476	15306
05 Jan 2010	21459	16203
Sujata		
25 Nov 2009	22148	16323
05 Dec 2009	21563	15849
15 Dec 2009	21051	15524
25 Dec 2009	21164	15851
05 Jan 2010	22527	16991
Amar		
25 Nov 2009	22148	16323
05 Dec 2009	21563	15849
15 Dec 2009	21051	15524
25 Dec 2009	21164	15851
05 Jan 2010	22527	16991

RAKH DHIANSAR

Validation of Campbell and Diaz Model

To validate this model for wheat crop, the periodic (10 days interval) dry matter observed in wheat varieties PBW-343, RSP-560, RSP-561 and RSP-529 during *rabi* 2009-10 were utilized. The soil specific input parameters, *viz*., field capacity, permanent wilting point and air dryness were assumed to be 0.25, 0.09 and 0.02, respectively. The maximum rooting depth and extinction coefficient of all four varieties were taken as 1.5 metres and 0.4, respectively. The initial biomass of varieties was taken as 0.0035 to 0.0037 g m^{-2}. The 1:1 relationship between simulated and observed dry matter at 10 days interval (Fig.4.1) showed that the model simulated dry matter production (g/m^2) with high accuracy (R^2 > 0.96) in all the four varieties of wheat.

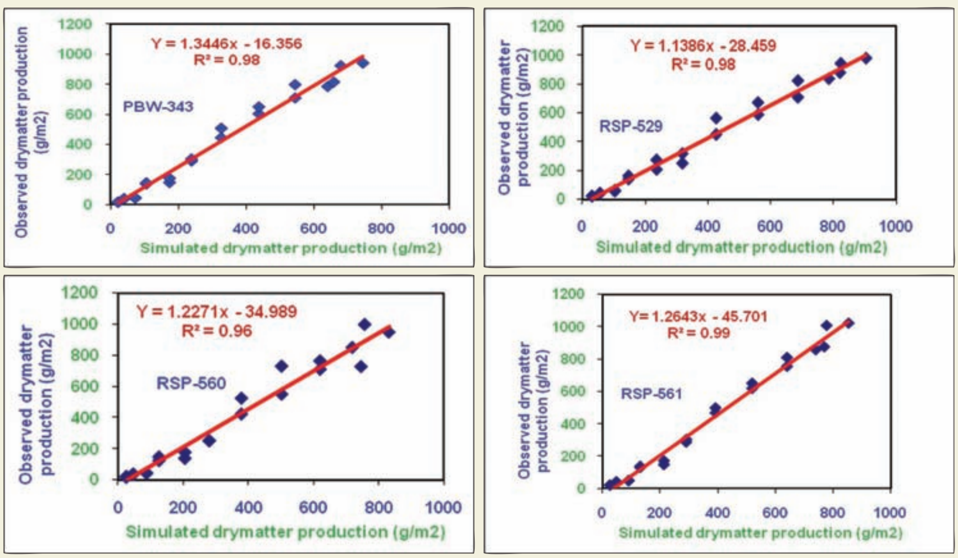


Fig.4.1. Simulated and observed drymatter production (g/m^2) in Wheat at Rakh Dhinsar

RANICHAURI

Drymatter partitioning

Partitioning (%) of drymatter into different plant components at four important phenological stages, *viz*., tillering, jointing, anthesis and maturity in respect of two varieties,, UP-1109 and Sonalika under three dates of sowing, *viz*., 30th Oct, 20th Nov and 10th Dec 2009 (Table 4.7) showed that roots were the prime sinks (41 to 53%) for drymatter at tillering stage in both varieties and three sowing dates. At jointing stage, higher percentage of drymatter was allocated to leaves than other plant organs while at anthesis, maximum (40 to 44%) allocation of drymatter was made to stem. At maturity stage, panicle got highest allocation (35 to 39%) of drymatter among the other plant organs.

Table 4.7. Partitioning of drymatter into different plant parts of two wheat varieties under three dates of sowing at Ranichauri

Treatment	Root	Stem	Leaf	Panicle
Tillering stage				
1st Date of sowing				
UP-1109	41	20	39	0
Sonalika	44	16	40	0
2nd Date of sowing				
UP-1109	44	11	45	0
Sonalika	53	10	37	0
3rd Date of sowing				
UP-1109	46	6	48	0
Sonalika	45	6	49	0
Jointing stage				
1st Date of sowing				
UP-1109	24	26	37	13
Sonalika	20	23	42	15
2nd Date of sowing				
UP-1109	21	28	39	12
Sonalika	23	25	36	16
3rd Date of sowing				
UP-1109	21	27	33	19
Sonalika	23	27	39	11
Anthesis stage				
1st Date of sowing				
UP-1109	15	44	20	21
Sonalika	14	43	25	18
2nd Date of sowing				
UP-1109	20	40	23	17
Sonalika	15	44	24	17
3rd Date of sowing				
UP-1109	15	44	24	17
Sonalika	17	42	23	18
Maturity stage				
1st Date of sowing				
UP-1109	18	28	15	39
Sonalika	19	31	14	36
2nd Date of sowing				
UP-1109	20	31	14	35
Sonalika	16	30	15	39
3rd Date of sowing				
UP-1109	19	29	16	36
Sonalika	19	29	13	39

SAMASTIPUR

Perusal of data on days taken and heat unit requirement for reaching different phenological stages of wheat under different dates of sowing and varieties (Table 4.8) showed that days taken for all phenological stages declined (except tillering stage) with delay in sowing. The heat unit requirement, however, decreased with delay in sowing up to 15th July 2009 and started increasing with further delay in sowing in all the phenophases, except tillering and maturity stages. The heat units required for maturity were highest (1783.8°C day) under early sowing (25th Nov) and lowest (1592.5°C day) in late (25th Dec) sown crop. The degree days requirement for different phenological stages did not vary much across different genotypes.

Table 4.8. Effect of sowing dates on phenophases and heat unit accumulation of wheat varieties at Samastipur

Treatments	Tiller initiation		Boot stage		50% ear head emergence		Milk stage		Dough stage		Maturity	
	DAS	GDD	DAS	GDD	DAS	GDD	DAS	GDD	DAS	GDD	DAS	GDD
Sowing dates												
25.11.09	32.0	419.7	75.8	813.9	88.3	980.3	96.0	1098.5	122.6	1612.2	130.0	1783.8
05.12.09	30.8	344.0	73.7	765.8	83.4	833.5	92.4	1055.5	116.0	1527.2	121.9	1665.3
15.12.09	30.8	298.8	67.2	681.6	77.6	838.9	84.8	965.7	107.8	1333.1	114.4	1596.1
25.12.09	31.0	247.8	65.6	684.9	74.8	845.3	82.7	982.8	101.7	1409.0	108.7	1592.5
CD (0.05)	**0.87**	**6.9**	**1.616**	**18.4**	**0.79**	**39.7**	**0.96**	**16.5**	**0.59**	**105.2**	**0.51**	**16.0**
Varieties												
HD 2824	30.7	326.5	71.2	745.3	82.0	905.3	89.8	1041.6	112.6	1457.8	118.8	1669.3
K 307	31.6	331.9	69.8	727.0	79.2	829.6	87.6	1000.9	111.1	1475.1	118.5	1650.8
CBW 38	30.8	324.7	69.2	717.3	79.8	840.1	87.7	1003.2	111.3	1479.1	118.3	1646.3
HD 2733	31.4	327.2	72.0	756.6	83.0	922.9	90.8	1056.8	113.1	1469.6	119.3	1671.2
CD (0.05)	**0.87**	**NS**	**1.16**	**18.4**	**0.79**	**39.7**	**0.96**	**16.5**	**0.59**	**NS**	**0.51**	**16.0**

(DAS: Days after sowing; GDD = Growing Degree Days)

Rabi SORGHUM

BIJAPUR

The WOFOST crop growth simulation model was calibrated with data from three-year field experimentation (2006-09). The WOFOST model is a comprehensive simulation model which takes into account the factors including, crop growth, radiation, growing degree days along with rainfall and soil moisture.

The model provided accurate yield estimation in case of early sown crop of 15^{th} Sept with only 4.2 per cent error (Table 4.9). In the year 2009, the percentage error in estimated grain yield is between -17.4 to 26.5. Therefore, the yield prediction of sorghum genotype M35-1 can be termed as moderately good and the errors in estimation increased with delayed sowings. Overall, the model provides a mean error of 13.7 per cent. The standard deviation is 87.8 kg/ha with a Root Mean Square Error of 531 kg/ha.

Table 4.9. Validation of WOFOST Model *for rabi* sorghum at Bijapur

Date of sowing	Grain Yield (kg ha^{-1})		
	Observed	Predicted	% Error
15.9.06	1246	1186	-4.8
29.9.06	1907	1191	-37.5
9.10.06	1608	1010	-37.2
21.9.07	1312	1061	-19.1
1.10.07	1906	896	-53.0
22.10.07	1090	626	-42.6
19.9.08	314	1136	261.8
6.10.08	720	940	30.6
15.09.2009	1399	1458	4.2
06.10.2009	1226	1551	26.5
16.10.2009	1787	1475	-17.4
Average	**1319.5**	**1139.1**	**-13.7**
Std. Dev.	**493.4**	**278.2**	**87.8**
RMSE		**531**	

It can be noticed from the Table 4.10 that in the case of early sowing of the crop on 15^{th} Sept 2009, the model could evaluate both the flowering time and maturity within tolerable limits of four days and two days, respectively. The percent error of the model in the estimation of anthesis is between -5.7 to -7.7 and physiological maturity is -1.8 to -3.9.

Table 4.10. Comparison of simulated *versus* observed phenological events at Bijapur

Date of sowing	Flowering (Days after sowing)			Physiological maturity (Days after sowing)		
	Observed	Predicted	% Error	Observed	Predicted	% Error
15.09.2009	70	66	-5.7	110	108	-1.8
06.10.2009	67	62	-7.5	106	102	-3.8
16.10.2009	65	60	-7.7	101	97	-3.9

(% Error = (Predicted – Observed) / Observed * 100)

SOLAPUR

Growing degree days

Requirement of growing degree days for occurrence of different phenological stages (Table 4.11) in three varieties, M 35-1 (V_1), Mauli (V_2), and Vasudha (V_3) under four dates of sowing, *viz*., 11st Sept (S_1), 22nd Sept (S_2), 1st Oct (S_3) and 17th Oct (S_4) showed that degree day requirement from sowing to maturity was highest (1658-1963°C day) in 1st Oct sown crop varieties. Among the varieties, M 35-1 required highest number of growing degree days and Vasudha required lowest number of degree days for reaching all the phenological stages under all the dates of sowing.

Table 4.11. Growing degree days required to attain phenological stages as influenced by sowing dates in *rabi* sorghum

Date of Sowing/ Variety	Phenological stage							
	Emergence	3 leaf	PI	Flag leaf	50% flowering	Soft dough	Hard dough	Phy. Maturity
S_1V_1	76	158	497	1011	1247	1479	1675	1890
S_1V_2	65	136	437	876	1023	1242	1410	1575
S_1V_3	71	143	428	926	1128	1352	1538	1746
S_2V_1	88	181	532	1018	1260	1504	1712	1930
S_2V_2	70	146	452	896	1048	1272	1443	1612
S_2V_3	80	159	453	960	1171	1404	1601	1818
S_3V_1	97	200	520	1040	1267	1520	1736	1963
S_3V_2	76	158	470	919	1077	1306	1483	1658
S_3V_3	89	176	479	997	1214	1454	1658	1882
S_4V_1	79	161	477	975	1183	1412	1604	1809
S_4V_2	68	142	446	888	1037	1259	1430	1598
S_4V_3	72	145	432	931	1136	1362	1551	1762

MUSTARD

HISAR

The thermal time requirement or heat units (HU) for completion of different phenological stages of *Brassica* cultivars under different sowing environments were worked out and are presented in the Table 4.12. The cumulative thermal time requirements were significantly higher at all phenological stages in the 14th Oct (D_1) sown crop followed by 27th Oct (D_2) and 7th Nov (D_3) sown crop. These values at physiological maturity were 1635.1, 1563.6 and 1466.7°C day for D_1, D_2 and D_3, respectively. Among the *Brassica juncea* varieties, Kranti accumulated highest heat units (1560.1°C day) followed by RH 30 (1548.6°C day). Among the *Brassica napus* genotypes, HNS- 0403 accumulated significantly higher thermal time (1652.3°C day) as compared to other genotypes.

The *Brassica* crop sown on 14th Oct accumulated more thermal units as compared to 27th Oct and 7th Nov sown crops because early sown crop took more days to mature as compared to late sown crop.

Table 4.12. Effect of sowing dates and genotypes on accumulated heat units (° day) to attain different phenophases in mustard at Hisar

Treatments	Emergence	5th Leaf	Flower bud visible	First flower opened	Flowering at (%)		Seed Filling		Phy. Maturity
					50	100	Start	End	
Sowing Date									
14th Oct	55.4	357.0	561.2	678.0	827.6	898.4	918.7	1420.7	1635.1
27th Oct	70.1	338.7	605.2	681.5	802.8	858.5	875.2	1342.2	1563.6
7th Nov	65.1	339.5	540.2	613.4	723.6	772.9	791.0	1273.0	1466.7
CD at 5%	**10.5**	**11.2**	**8.01**	**10.2**	**6.30**	**7.39**	**7.40**	**8.54**	**10.1**
Varieties									
V_1*	61.2	342.2	568.2	655.8	749.7	814.8	835.5	1315.1	1630.6
V_2	63.8	348.6	569.9	659.0	888.8	919.2	934.5	1430.6	1648.3
V_3	63.8	343.3	569.9	660.6	750.7	818.7	836.7	1316.4	1630.6
V_4	65.2	346.3	567.4	655.2	749.6	820.3	839.7	1318.9	1652.3
V_5	63.8	342.2	569.9	660.6	888.8	919.2	935.6	1356.8	1648.3
V_6	61.2	342.2	568.2	655.8	750.7	820.3	835.6	1318.9	1548.6
V_7	61.2	342.2	568.2	655.8	749.6	818.7	835.5	1316.8	1516.3
V_8	63.8	346.3	569.9	660.6	750.7	820.3	839.7	1318.9	1560.1
V_9	63.8	346.3	569.9	659.0	886.2	919.2	934.5	1430.6	1524.2
V_{10}	63.8	346.3	569.9	659.0	888.8	919.2	934.5	1378.6	1524.2
CD at 5%	**NS**	**NS**	**NS**	**NS**	**5.88**	**5.91**	**5.13**	**7.11**	**11.1**

(*V_1 = GSL-1, V_2 = HNS-401, V_3 = HNS-000, V_4 = HNS-0403, V_5 = HNS-0501, V_6 = RH-30, V_7 = Laxmi, V_8 = Kranti, V_9 = Varuna and V_{10} = RH-819)

LUDHIANA

The data on degree day requirement (stage-wise and cumulative) of *brassica* species under three dates of sowing, *viz*., 30th Oct, 6th Nov, 13th Nov and 20th Nov 2009 and three different varieties, *viz*., PBR-91, GSL-1 and Hyolla-PAC-401 are given in Table 4.13. The perusal of data indicates that early sown *brassica* cultivars accrued more growing degree days to attain physiological maturity as compared to late sown *brassica* cultivars. Among the three cultivars, GSL-1 accrued highest number of growing degree days for maturity under all the sowing dates, i.e., 1820, 1698, 1620 and 1616°C day under first, second, third and fourth dates of sowing, respectively.

Table 4.13. Growing-degree days (GDD) accrued by *Brassica* cultivars under four dates of sowing during 2009 at Ludhiana

Phenological events	30th Oct	06th Nov	13th Nov	20th Nov
PBR-91				
Sowing - Start emergence	71(71)	60(60)	69(69)	66(66)
Start -Complete emergence	83(154)	67(127)	53(122)	55(121)
Complete emergence - Start Flowering	445(559)	426(553)	489(611)	455(576)
Start Flowering –Start Pod formation	68(667)	59(612)	94(705)	101(677)
Start Pod Formation – Start Pod filling	111(778)	98(710)	139(844)	123(800)
Start Pod Filling - Physiological Maturity	799(1577)	811(1521)	579(1423)	638(1438)
GSL-1				
Sowing - Start emergence	71(71)	60(60)	69(69)	66(66)
Start -Complete emergence	96(167)	81(141)	75(144)	66(132)
Complete emergence - Start Flowering	629(796)	590(731)	578(722)	584(716)
Start Flowering –Start Pod formation	130(926)	162(893)	102(824)	107(823)
Start Pod Formation – Start Pod filling	78(1004)	89(982)	60(884)	68(891)
Start Pod Filling - Physiological Maturity	816(1820)	716(1698)	736(1620)	725(1616)
Hyolla PAC-401				
Sowing - Start emergence	71(71)	60(60)	69(69)	66(66)
Start -Complete emergence	96(167)	67(127)	64(133)	77(143)
Complete emergence - Start Flowering	523(690)	521(648)	516(649)	504(647)
Start Flowering –Start Pod formation	100(790)	72(720)	134(783)	124(771)
Start Pod Formation – Start Pod filling	48(838)	74(794)	51(834)	51(822)
Start Pod Filling - Physiological Maturity	914(1752)	836(1630)	676(1510)	664(1486)

(Figure in parenthesis is cumulative growing degree days)

UDAIPUR

Validation of yield prediction models

The growing degree days based yield prediction models using the data of previous year (2008-09) were validated with actual yield during the year 2009-10 (Table 4.14). It was revealed from the data that seed yield prediction was more accurate (% error of 0.3 to 5) under early or normal sowing (5^{th} to 20^{th} Oct) with two irrigations. However, these prediction equations failed to predict seed yield accurately in later sowing dates. Under three irrigations the yield prediction was more accurate in early sown crop (5^{th} Oct) with percentage error of -2.1 per cent only.

Table 4.14. Seed yield prediction during 2009 at Udaipur

Irrigation level	Regression equation	Date of sowing	GDD in 2009-10 (q/ha)	Predicted seed yield (q/ha)	Actual seed yield	Deviation from predicted (%)
Two	Y = 3.088 + 0.0116 GDD	5^{th} Oct	1806	24.04	22.84	5.0
		20^{th} Oct	1692	22.72	22.64	0.3
		4^{th} Nov	1640	22.11	13.37	39.5
		19^{th} Nov	1587	21.50	11.42	46.9
Three	Y = - 43.455 + 0.0353 GDD	5^{th} Oct	1873	22.66	23.13	-2.1
		20^{th} Oct	1674	15.64	22.39	-43.2
		4^{th} Nov	1734	17.76	16.46	7.3
		19^{th} Nov	1608	13.31	11.45	14.0

Growing degree days (GDD)

Number of days taken and cumulated growing degree days required for vegetative and reproductive period as well as total growing period under four dates of sowing and irrigation levels (Table 4.15) brought out that early sown crop required more number of days (116) and degree days (1759°C days) for maturity than the late sown crop. Irrigation levels increased the duration as well as cumulative degree days requirement of crop maturity and the crop with three irrigation levels had 11 days more longer duration and required 164°C days higher GDD than the crop with no irrigation. The duration of vegetative period was shorter by 3 to 6 days and that of reproductive period was longer by 12 days under early sowing compared to late sowing. Similar pattern of fewer growing degree days for vegetative stage (735°C day) and higher GDD for reproductive period (1024°C day) under early sowing than under delayed sowing is observed.

Table 4.15. Number of days and accumulated GDD required for attaining different phenophases of mustard under varying environments and irrigation levels at Udaipur

Treatment	Phenophases	No irrigation	One irrigation	Two irrigations	Three irrigations	Mean
5th Oct 2009 (D_1)	Vegetative	713(37)	732(38)	747(39)	747(39)	735(38)
	Reproductive	955(73)	955(73)	1051(80)	1134(86)	1024(78)
	Total	**1668(110)**	**1687(111)**	**1798(119)**	**1881(125)**	**1759(116)**
20th Oct 2009 (D_2)	Vegetative	617(37)	632(38)	646(39)	660(40)	639(39)
	Reproductive	930(72)	929(72)	1019(78)	1048(80)	982(76)
	Total	**1547(109)**	**1561(110)**	**1665(117)**	**1708(120)**	**1620(115)**
4th Nov 2009 (D_3)	Vegetative	637(42)	654(43)	654(43)	669(44)	654(43)
	Reproductive	848(67)	847(67)	882(69)	932(72)	877(69)
	Total	**1485(109)**	**1501(110)**	**1536(112)**	**1601(116)**	**1531(112)**
19th Nov 2009 (D_4)	Vegetative	582(40)	593(41)	593(43)	614(45)	596(42)
	Reproductive	885(65)	928(67)	981(68)	1020(68)	954(67)
	Total	**1467(105)**	**1521(108)**	**1574(111)**	**1634(113)**	**1549(109)**
Mean	Vegetative	637(39)	653(40)	660(41)	673(42)	656(41)
	Reproductive	905(69)	915(70)	983(74)	1034(77)	959(73)
	Total	**1542(108)**	**1568(110)**	**1643(115)**	**1706(119)**	**1615(113)**

(Figures in parenthesis are number of days)

Harvest index

Harvest index, an important component of crop simulation models was worked out for mustard under four dates of sowing and irrigation levels. The harvest index values (Table 4.16) were more influenced by irrigation levels (24.0 to 30.1) than sowing dates (24.8 to 30.2). Highest harvest index (30.2 %) is achieved in early sowings (5th-20th Oct) as well as with two irrigations (31.0%).

Table 4.16. Effect of different sowing environment and irrigation levels on seed yield and harvest index of mustard (2008-09 & 2009-10) at Udaipur

Sowing dates	Harvest Index (%)		
	2009-10	**Irrigation levels**	**2009-10**
5th Oct 2009 (D_1)	30.2	I_0	24.0
20th Oct 2009 (D_2)	30.2	I_1	27.5
4th Nov 2009 (D_3)	27.2	I_2	31.0
19th Nov 2009 (D_4)	24.8	I_3	30.1
SEm ±	**0.49**	**SEm ±**	**0.36**
CD (P=0.05)	1.38	CD (P=0.05)	0.99

5. WEATHER EFFECTS ON PESTS AND DISEASES

SAFFLOWER

AKOLA

Aphids population in safflower under four different micro-weather conditions imposed by sowing crop on four different weeks 40, 41, 42 and 43 SMW of 2009 were analyzed in relation to weather conditions for establishing pest and weather relationships.

Pest-weather relationships

Correlation coefficients of aphids population with weather parameters during different lag periods (0, 1, 2 and 3 weeks) of peak aphid incidence (Table 5.1) revealed that maximum, minimum and mean temperatures at all lag periods bear significant negative relation while morning and mean relative humidity at all lag periods had significant positive relationship with aphids population.

Table 5.1. Correlation of aphids and weather parameters at different times in safflower at Akola

Parameters	Lag period (Week)			
	0	1	2	3
MaxT	-0.586**	-0.614**	-0.421*	-0.436**
MinT	-0.639**	-0.579**	-0.398**	-0.316*
MeanT	-0.633**	-0.621**	-0.431**	-0.389**
RH_I	0.436**	0.477**	0.560**	0.579**
RH_{II}	-0.053	0.012	0.065	0.112
RH_{mean}	0.359*	0.387*	0.571**	0.576**
BSH	-0.144	-0.293	0.019	0.257

Regression of aphids population with weather parameters (Fig.5.1) indicated highly significant inverse relationship of aphids population with both minimum and maximum temperature and significant positive relationship with morning relative humidity. From the above relations, lower maximum temperature of around 27°C and minimum temperature of 7 to 8°C and higher morning relative humidity of 73 per cent were found to be congenial for aphids population in safflower.

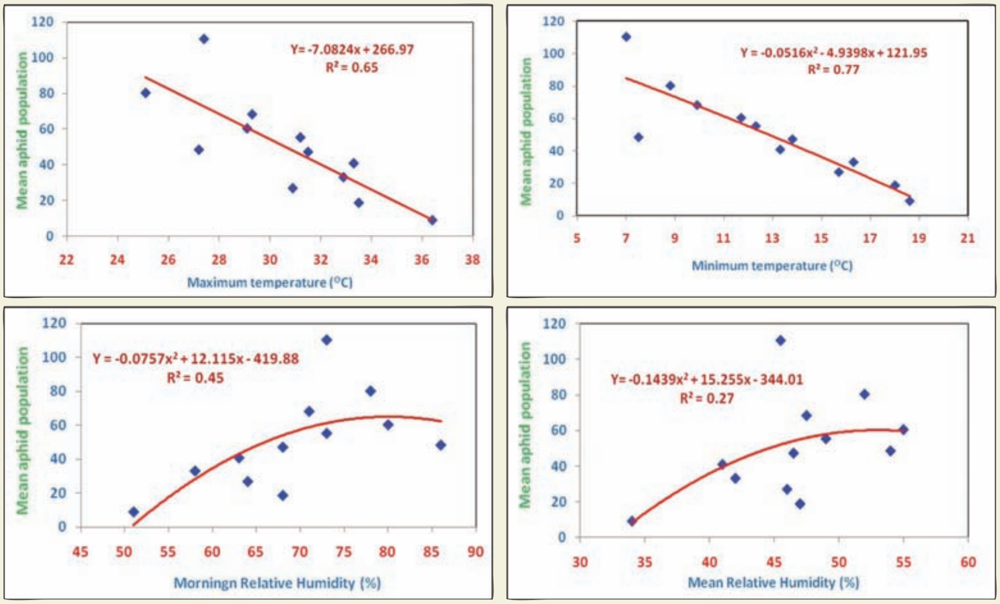


Fig. 5.1. Effect of weather parameters on aphids population in Safflower at Akola

MUSTARD

ANAND

Analyzing six years pest/disease data on stem rot, rust and sawfly in relation to weather parameters in different stages of crop, pest/disease and weather relationships were developed (Table 5.2). It was observed from the regression equations that weather parameters could significantly influence sawfly with minimum standard error of estimate. In late sown mustard, afternoon relative humidity during vegetative period inversely affected the sawfly pest and low humidity during vegetative period favoured higher pest population.

UDAIPUR

Effect of weather on aphids population

Correlation coefficients of aphids population on top 10 cm inflorescence of mustard with weather parameters, *viz.*, maximum, minimum and mean temperatures and mean relative humidity during initiation of peak infestation period (Table 5.3) revealed that aphids population is negatively related with maximum, minimum and mean temperature. However, mean temperature is more significantly related with aphids population than maximum or minimum temperature. Mean relative humidity is not showing any significant influence on aphids population.

Table 5.2. Weather-based pest-disease forecasting model in mustard at Anand

Disease/ pest	Dates of sowing	Regression Equations	R^2 (SEE)
Stem rot	D_1-10th Oct	Y= 42.332 -0.415 RH_1 (FL & POD*)	0.32 (5.82)
	D_2-20th Oct	Y= 51.683 -0.643 MRH(FL & POD) - 0.371 MinT (FL & POD)	0.55(5.06)
	D_3-30th Oct	Y= -59.497 -0.833 MinT (FL & POD) + 16.491 EP(FL & POD) + 2.410 VP_2(FL & POD)	0.78(5.83)
Rust	D_1-10th Oct	Y=-73.463 +13.650EP (POD & PM) + 3.564 VP1 (POD & PM)	0.76(4.38)
	D_2-20th Oct	Y=9.414 +7.010EP(POD & PM) -0.957 MaxT(POD & PM)	0.76(5.19)
	D_3-30th Oct	Y=-13.373 +5.939 MeanT (POD & PM) -1.471 MaxT (POD & PM)	0.92(1.67)
		Y=-5.342 +6.140 MeanT (POD & PM) -1.699 MaxT (POD & PM) -1.291 BSS (POD & PM)	0.96(1.20)
Saw fly	D_2-20th Oct	Y=-0.654 +2.283 MRH(VEG) -0.156WS(VEG)	0.50(0.15)
	D_3-30th Oct	Y=1.855 -4.0 RH2(VEG)	0.48(0.33)
	D_4-10th Nov	Y=0.239 -3.4 RH2(VEG)+0.365EP(VEG)	0.71(0.26)

(* VEG, FL, POD, PM represent vegetative, flowering, pod formation and physiological maturity stages, respectively)

Table 5.3. Correlation between number of aphids and weather parameters in mustard during 2009-10 at Udaipur

Sowing date	Temperature (°C)			Mean RH
	Mean	Maximum	Minimum	
5th Oct (D_1)	-0.616	-0.574	-0.489	0.216
20th Oct (D_2)	-0.785	-0.639	-0.724	0.308
4th Nov (D_3)	-0.777	-0.596	-0.757	0.308
19th Nov (D_4)	-0.575	-0.425	-0.578	0.169

Kharif 2010

6. CROP-WEATHER RELATIONSHIPS

SOYBEAN

AKOLA

To study crop-weather relationships in soybean, three varieties, *viz.*,JS-335, TAMS-38 and TAMS-98-21 were subjected to four different temperature and moisture regimes by sowing crop on four dates, *viz.*, 1st, 8th, 15th and 22nd July 2010.

Crop-weather relationships in soybean

The correlation coefficients of weather variables prevailed during different phenological stages and seed yield (Table 6.1) showed that during vegetative stage, temperature related weather variables like maximum and mean temperature, growing degree days (GDD) and heliothermal units (HTU) positively and significantly influenced the seed yield. During the pod formation (PF) to full seed development phase, rainfall, minimum temperature and relative humidity showed highly significant positive relation with yield.

Maximum and mean temperature during seed formation to full seed development stage, however, showed significant negative relationship with yield. Mean seed yield of four dates of sowing in the years 2007-2010 were related with temperature (maximum, minimum and mean) and rainfall during vegetative, reproductive and total growing period of soybean. Out of all these parameters, only rainfall during all the three stages showed significant positive relationship with yield (Fig. 6.1).

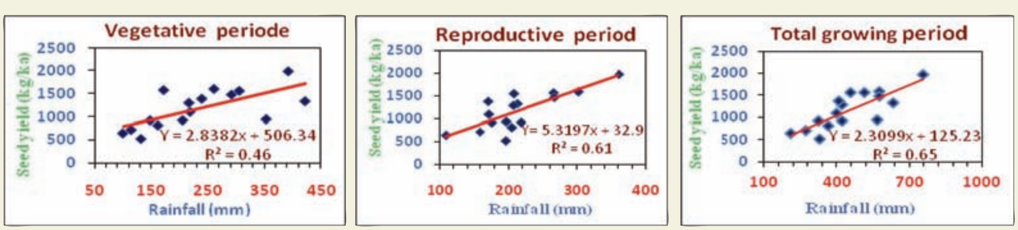


Fig.6.1. Yield of soybean as influenced by rainfall during different stages of crop at Akola

Influence of weather indices on yield and yield attributes

Yield and yield attributes of soybean along with weather indices (Table 6.2) revealed that highest yield and yield attributes were recorded in early sown (1st July) crop due to higher water use and accumulated GDD during the total growing period, higher rainfall during the reproductive period and higher percentage of interception of radiation during flowering to pod formation stage than in successive late sown crops.

Table 6.1. Correlation coefficients between seed yield and weather variables prevailed during different phenophases of soybean at Akola

Parameters	Vegetative phase	Flowering	Pod formation	Seed formation	Full seed development	Physiological maturity	Total growing period
Rainfall	0.142	0.274	0.958**	0.691**	0.875**	-0.806**	0.747**
MaxT	0.783**	0.444	-0.490	-0.908**	-0.872**	0.854**	0.061
MinT	0.441	0.821**	0.723**	0.871**	0.876**	-0.788**	0.833**
MeanT	0.642**	0.671**	-0.418	-0.829**	-0.723**	0.850**	0.492
RH_I	-0.352	0.841**	0.911**	0.654**	0.884**	-0.631**	0.342
RH_{II}	-0.006	-0.422	0.750**	0.860**	0.860**	-0.767**	0.384
RH_{Mean}	-0.124	-0.322	0.796**	0.842**	0.866**	-0.743**	0.341
GDD	0.931**	0.898**	0.812**	-0.804**	0.783**	0.757**	0.941**
HTU	0.770**	0.187	-0.456	-0.906**	0.772**	0.828**	0.815**

(* Significant at 0.05 level ** Significant at 0.01 level)

Table 6.2. Influence of weather indices on yield and yield attributes of soybean during kharif 2010 at Akola

Treatment	Yield (kg/ha)		Yield attributes		Rainfall (mm) during flowering to maturity	Water use (mm)	Radiation interception (%)		Accumulated GDD (°C day)
	Seed	Biomass	Plant height (cm)	Pods per plant			Flowering stage	Pod formation stage	
Sowing date									
1 July	1976	4766	60.0	44.9	364	328	53.4	75.7	1756
8 July	1593	4094	55.1	33.4	313	323	49.8	72.7	1724
15 July	1469	3843	52.9	28.8	285	311	43.0	71.3	1668
23 July	940	2610	48.0	23.0	214	294	36.9	59.8	1581
CD (0.05)	**157**	**477**	**6.15**	**2.66**	-	-	-	-	-
Variety									
JS-335	1680	3802	49.6	38.4	297	314	45.2	70.2	1671
TAMS-38	1473	3693	52.2	30.3	282	298	46.5	67.0	1613
TAMS-98-21	1331	4033	60.2	29.0	281	330	45.6	72.4	1763
CD (0.05)	**136**	**143**	**5.3**	**2.3**	-	-	-	-	-

Heat and water use efficiency

Heat and water use efficiency in terms of yield of soybean (Table 6.3) showed early sown crop registering higher heat and water use efficiency compared to the late sown crop. Among the varieties, JS-335 achieved highest heat and water use efficiencies. The higher heat and water use efficiencies in case of early sowing and JS-335 were also reflected in their higher yields.

Table 6.3. Heat and water use efficiency of three soybean varieties sown on four different dates during *kharif* 2010 at Akola

Treatment	Heat use efficiency (kg ha^{-1}/°C day)	Water use efficiency (kg ha^{-1} mm^{-1})
Sowing date		
1st July	1.13	6.03
8th July	0.93	4.93
15th July	0.88	4.72
23rd July	0.60	3.20
Variety		
JS-335	1.00	5.36
TAMS-38	0.91	4.95
TAMS-98-21	0.75	4.03

JABALPUR

Crop-weather relationships in soybean were studied by exposing three crop varieties, *viz*., JS-335 (V_1), JS-93-05 (V_2) and JS-97-52 (V_3) to three different sets of weather conditions by sowing the varieties on three different dates – 1st July (D_1), 15th July (D_2) and 30th July (D_3). Yield and yield attributes along with weather parameters and weather indices during important phenological stages (Table 6.4) showed that both yield and yield attributes like plant height and number of branches per plant are positively related with per day weather indices, *viz*., growing degree days (GDD) and photothermal units and rainfall during the reproductive period. Heliothermal units (per day) during reproductive period, however, showed negative influence on seed yield and yield attributes. All the varieties sown on early date (1st July 2010) could register higher yield as well as yield attributes than in late sowing due to higher photothermal units, growing degree days and rainfall during reproductive period.

Table 6.4. Seed yield and yield attributes of soybean as influenced by weather parameters/ indices during 2010 at Jabalpur

Date of sowing/ Variety	Plant height (cm)	No. of branches/ plant	Yield (kg/ha)	GDD/ day (°C)	HTU / day (°C hr)	PTU / day (°C hr)	Rainfall (mm)	
							Vege-tative	Repro-ductive
1st July								
JS-335	65.3	7.3	820	17.7	83.4	217.7	573	852
JS-93-05	65.2	7.3	1000	17.7	83.4	217.7	778	662
JS-97-52	67.3	8.6	1000	17.7	83.4	217.7	763	758
15th July								
JS-335	64.9	6.3	640	16.7	96.0	200.4	637	620
JS-93-05	66.2	5.3	820	16.7	96.0	200.4	688	601
JS-97-52	67.2	7.7	1720	16.7	96.0	200.4	688	601
30th July								
JS-335	59.6	4.0	420	15.7	112.6	182.1	787	284
JS-93-05	61.9	4.3	580	15.7	112.6	182.1	983	97
JS-97-52	66.5	6.4	1430	15.7	112.6	182.1	923	201

PARBHANI

To study the influence of weather on growth and yield of soybean, six varieties of crop, *viz*., MAUS-158, JS-93-05, MAUS-47, MAUS-71, MAUS-81 and JS-335 were sown on 8th, 15th, 22th and 30th July 2010.

Crop-weather relationships in soybean

Correlation coefficients between yield and weather parameters during different phenological stages of the crop (Table 6.5) brought out that rainfall and soil moisture content (SMC) during pod formation stage had highly significant positive relationship with yield. During seed formation stage, maximum temperature, temperature range and bright sunshine hours showed highly significant positive relationship with seed yield. During seed development stage, relative humidity (morning, afternoon and mean) and soil moisture influenced the yield significantly and positively while maximum temperature and bright sunshine hours showed significant inverse relationship with yield.

Table 6.5. Correlation coefficients between seed yield and weather variables prevailed in different phenophases of Soybean during 2010 at Parbhani

Parameters	Pod formation	Seed formation	Pod development	Seed development
Rainfall	0.47**	- 0.08	0.28	0.00
Rainy days	0.28	- 0.12	0.35*	0.30
T_{Max}	- 0.04	0.44**	- 0.25	- 0.59**
T_{Min}	0.27	0.31	- 0.15	0.13
T_{Mean}	0.10	0.23	0.17	- 0.62
T_{Range}	- 0.25	0.52**	- 0.28	- 0.51
RH_{I}	- 0.33	0.06	0.34	0.49**
RH_{II}	- 0.09	- 0.08	0.29	0.56**
RH_{Mean}	- 0.33	- 0.04	0.27	0.52**
BSS	0.01	0.44**	- 0.27	- 0.49**
SMC	0.41**	- 0.227	- 0.14	0.73**

(* Significant at 5% ** Significant at 1%)

COTTON

AKOLA

To study the effect of weather conditions on seed yield of cotton, Ankur-651, the early duration Bt cotton hybrid was subjected to three different sets of weather conditions by sowing the crop on 8th June, 24th June and 9th July 2010. In addition to three different dates of sowing, four adaptation strategies, *viz.*, conventional practice, conservation furrows, dead mulch and live mulch were imposed.

Crop-weather relations

The correlation coefficients between seed cotton yield and weather parameters prevailed during different phenological stages as well as the total growing period (Table 6.6) showed that rainfall and rainy days at all the phenological stages except first boll burst to first picking showed highly significant positive relationship with yield. All the weather parameters and weather indices except relative humidity (RHI, RHII and RH_{Mean}) during the total growing period significantly and positively influenced cotton seed yield.

Heat and water use efficiency

Heat use efficiency (HUE) and water use efficiency (WUE) in terms of seed yield of cotton grown under three sowing dates and four adaptation strategies (Table 6.7) revealed that successive delay in sowing caused drastic reduction in both HUE and WUE. However, HUE and WUE did not show any substantial change due to different adaptation strategies.

Table 6.6. Correlation coefficients between seed cotton yield and weather variables prevailed in different phenophases of cotton at Akola

Parameters	S-EM	EM-FS	FS-FF	FF-FBB	FBB-FP	FP-LP	EM-LP	Total growing period
Rainfall	0.912**	0.982**	0.892**	0.978**	-0.451	0.963**	0.977**	0.906**
Rainy day	0.884**	0.954**	0.941**	0.980**	-0.739**	0.973**	0.956**	0.911**
MaxT	0.940**	0.977**	-0.667*	-0.963**	0.439	0.941**	0.956**	0.963**
MinT	0.984**	0.924**	-0.979**	0.985**	-0.214	0.987**	0.986**	0.884**
MeanT	0.966**	0.974**	-0.763**	-0.951**	0.538	0.979**	0.980**	0.951**
RH_I	-0.957**	-0.971**	0.884**	0.985**	0.246	-0.884**	-0.979**	-0.822**
RH_{II}	-0.599	-0.971**	0.985**	0.986**	-0.309	0.265	-0.265	-0.546
RH_{Mean}	-0.956**	-0.917**	0.971**	0.984**	-0.335	-0.610	-0.522	0.061
GDD	0.970**	0.179	0.872**	0.916**	0.433	0.986**	0.987**	0.977**
HTU	0.949**	0.945**	-0.935**	-0.720**	0.977**	0.969**	0.987**	0.767**

(S- Sowing, EM—Emergence, FS-First square, FF-First flower, FBB-First boll burst, FP-First picking, LP-Last picking)
(* = Significant at 0.05 level** = Significant at 0.01 level)

Table 6.7. Heat and water use efficiency of cotton under different sowing dates and adaptation strategies at Akola

Treatment	Heat use efficiency (kg ha^{-1}/°C day)	Water use efficiency (kg ha^{-1}/mm)
Sowing date		
Dry sowing (8th June)	0.60	2.73
Monsoon sowing (24th June)	0.41	1.90
Late sowing (9th July)	0.22	1.03
Adaptation strategy		
Conventional practice	0.42	1.93
Conservation furrows	0.46	2.08
Dead mulch	0.44	2.00
Live mulch	0.40	1.79

PARBHANI

To study the effect of weather conditions on growth and yield of cotton, two varieties of cotton, *viz*., NHH-44 and NH-615 were grown under six different moisture and thermal regimes by sowing them on six dates, *viz*., 22nd June, 29th June, 6th July, 13th July, 20th July and 27th July 2010.

Yield and weather correlations

The correlation coefficients between yield and weather parameters during different phenological stages of the crop (Table 6.8) showed that the rainfall and rainy days during boll formation to first picking influenced the yield positively and significantly. Minimum and mean temperature during first and second pickings also showed significant positive relation with yield. The relative humidity (morning, afternoon and mean) showed highly significant positive relationship with yield only during boll formation to boll bursting stage. However, growing degree days at all the phenological stages had highly significant positive relationship with yield.

Table 6.8. Correlation coefficients exhibited by weather parameters prevailed in different phenophases with seed cotton yield at Parbhani

Parameters	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
Rainfall	- 0.60	- 0.18	- 0.53	- 0.46	0.10	0.96**	0.90**	- 0.29
Rany days	- 0.75*	0.30	- 0.41	- 0.32	0.23	0.92**	0.97**	- 0.38
T_{Max}	0.91**	0.34	0.35	0.42	- 0.23	- 0.68	0.69	0.87**
T_{Min}	0.65	0.81*	0.82	0.51	- 0.15	0.61	0.97**	0.98**
T_{Mean}	0.95**	0.61	0.49	0.44	- 0.21	0.47	0.89**	0.99**
RH_I	- 0.61	- 0.17	- 0.44	- 0.50	0.22	0.83**	- 0.29	- 0.69
RH_{II}	- 0.55	- 0.22	- 0.35	- 0.50	0.02	0.82**	0.51	0.56
RH_{Mean}	- 0.60	- 0.20	- 0.38	- 0.50	0.08	0.83**	- 0.17	0.43
BSS	0.78*	- 0.54	0.53	0.01	- 0.57	- 0.84	0.14	- 0.69
GDD	0.95**	0.96**	0.87**	0.93**	0.90**	0.97**	0.97**	0.98**

(*Significant at 5% level, ** Significant at 1% level)

P_1 = Sowing to emergence
P_2 = Emergence to seedling
P_3 = Seedling to square formation
P_4 = Square formation to flowering
P_5 = Flowering to boll setting
P_6 = Boll setting to boll bursting
P_7 = Boll bursting to 1st picking
P_8 = 1st picking to 2nd picking

GROUNDNUT

ANAND

For obtaining crop-weather relationships in groundnut, pod yield data of two varieties, *viz.*, Robut 33-1 and GG-2 sown on two dates, one with the onset of monsoon (D_1) and another 15 days after D_1 over last 12 years were analyzed in relation to weather conditions during different phenological stages of the crop.

Correlation coefficients between pod yield and weather parameters during different phenological stages of groundnut (Table 6.9) showed that in early sown groundnut, mean temperature (T_{Mean}) during pod development stage and in late sown groundnut, minimum temperature (T_{Min}) during pod development stage positively influenced the pod yield.

Table 6.9. Correlation coefficients between pod yield of groundnut and weather parameters during different phenological stages at Anand

Parameters	Emergence	Flowering	Pegging	50 % Pod develop-ment	Pod develop-ment	Maturity
D_1 (Sowing with onset of monsoon)						
BSS	0.17	-0.26	-0.41	0.01	0.53	-0.21
RF	-0.15	0.30	0.02	0.03	-0.45	0.27
T_{Max}	0.13	-0.34	-0.46	0.02	0.56	-0.01
T_{Min}	0.09	-0.51	-0.41	0.18	0.47	0.16
T_{Mean}	0.12	-0.39	-0.48	0.08	0.62*	0.12
RH1	-0.28	0.39	0.43	0.16	-0.43	0.09
RH2	0.01	0.44	0.49	0.01	-0.43	0.04
MRH	-0.07	0.43	0.50	0.06	-0.45	0.03
D_2 (Fifteen days after D_1 sowing)						
BSS	0.06	-0.08	0.12	0.15	-0.67*	-0.48
RF	0.50	0.43	0.53	-0.21	0.40	0.60
T_{Max}	-0.01	-0.23	0.21	0.19	-0.42	-0.33
T_{Min}	-0.21	0.00	0.44	0.76**	0.21	0.49
T_{Mean}	-0.05	-0.18	0.30	0.37	-0.25	0.14
RH1	0.26	0.38	0.10	-0.20	0.38	0.30
RH2	0.17	0.33	0.03	-0.02	0.48	0.45
MRH	0.21	0.36	0.05	-0.06	0.46	0.42

By regressing yield with weather parameters (minimum, maximum and mean temperatures) during pod development stage (Table 6.10), it was observed that temperature during this stage influenced the pod yield significantly.

Table 6.10. Regression equations relating pod yield of groundnut with temperature and stress degree days at Anand

Date of sowing/ variety	Regression equation	R^2
D_1 (Sowing with onset of monsoon)		
	$Y=-11134.1 + 468.301\ T_{Mean}\ (POD)$	0.38
D_2 (Fifteen days after D_1 sowing)		
	$Y= -12037.705 + 552.592\ T_{Min}\ (POD)$	0.58
	$Y=-8980.585 + 673.137\ PODMINT-215.433\ T_{Mean}\ (POD)$	0.85
	$Y=-13832.050+ 803.879\ T_{Min}\ (POD)-259.660\ T_{Mean}\ (POD) + 82.646\ T_{Max}\ (POD)$	0.92
GG-2	Y=4.379- 0.704 (SDD of 10th week)	0.81
Robut 33-1	Y=10.121 – 0.692 (SDD of 9th week)	0.53

Mean weather conditions and pod yield

The mean weather conditions in early (D_1) and delayed sowing (D_2) along with the yield in respective sowing dates (Table 6.11) showed that higher rainfall, rainy days, mean temperature per day and evapotranspiration contributed for higher pod yield in early sowing compared to delayed sowing.

Table 6.11. Pod yield of groundnut as influenced by weather conditions in different dates of sowing at Anand

Treatment	Pod yield (kg/ha)	Rainfall (mm)	Rainy days	Mean daily temperature (°C)	ET (mm)	Sunshine hours
D_1	2011	882.5	33.0	28.8	292	645
D_2	1751	700.4	28.5	28.5	283	660

ANANTAPUR

Crop-weather relationships in groundnut were studied by growing three varieties, *viz*., Vemana (V_1), K6 (V_2) and pre-release K-1271 (V_3) in three varied environmental conditions by sowing them on 8th July (D_1), 24th July (D_2) and 8th August (D_3) in the year 2010. Yield of groundnut varieties along with weather parameters during vegetative and reproductive periods of the crop (Table 6.12) revealed that the lower yield under late sown conditions compared to early and normal sown conditions was due to less rainfall, rainy days, lower temperature and low sunshine hours during reproductive period of the late sown crop.

Table 6.12. Pod yield (kg/ha) of groundnut varieties under different dates of sowing and weather conditions during 2010 at Anantapur

Weather conditions	D_1 (8th July)			D_2 (24th July)			D_3 (8th Aug)		
	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
Pod yield (kg/ha)	1530	1336	1648	927	772	1122	540	573	826
Rainfall (mm)									
Vegetative	171.8(82.6)			120.4(63.6)			260.4(96.1)		
Reproductive	508.6(335.4)			431.4(308)			261.0(235.2)		
Rainy days (No.)									
Vegetative	6			6			9		
Reproductive	25			24			19		
Temperature (°C)									
Vegetative	28.0(28.5)			27.8(28.1)			28.0(28.0)		
Reproductive	27.9(27.3)			26.9(27.1)			26.9(26.5)		
Sunshine hours									
Vegetative	3.2(5.2)			4.0(5.1)			5.1(5.8)		
Reproductive	5.0(6.9)			4.0(7.0)			3.9(7.3)		

(Values in parenthesis indicate normal value of the parameters)

RICE

KANPUR

To study the crop-weather relations in rice, three varieties, *viz*., NDR-359, CSR-27 and Sarjoo-52 were grown under three varied weather conditions, imposed by three transplanting dates, i.e., 16th July, 26th July and 5th August 2010.

Effect of weather on yield and yield attributes

The data on yield and yield attributing characters along with maximum and minimum temperature and rainfall during vegetative and reproductive periods of rice (Table 6.13) showed that all these parameters were higher in early sowing (16th July) than in late sowing (5th Aug) due to higher maximum and minimum temperature during vegetative period, higher minimum temperature and rainfall during reproductive period of early sown crop than in late sown crop.

Table 6.13. Yield and yield attributing characters of rice as influenced by weather conditions during 2010 at Kanpur

Date of sowing / Variety	Yield (kg/ha)		No. of rachily /ear	Length of ear (cm)	No. of grains /ear	1000 grain wt.(g)	T_{Max} (°C)		T_{Min} (°C)		Rainfall (mm)	
	Grain	Straw					Vege-tative	Repro-ductive	Vege-tative	Repro-ductive	Vege-tative	Repro-ductive
16th July	5320	6610	13.2	26.0	124.4	28.6	34.2	32.4	27.1	23.4	817	107
26th July	4730	6080	12.1	24.6	119.3	27.9	33.3	32.5	26.7	22.6	834	45
5th Aug	3990	5740	11.3	24.1	107.8	26.9	32.7	32.2	26.3	20.7	745	18
CD 5 %	**428**	**318**	**0.35**	**1.10**	**2.70**	**0.21**						
V_1	5100	6690	12.9	26.2	124.0	29.1						
V_2	4330	5760	11.9	24.5	110.8	27.8						
V_3	4610	5980	11.7	24.1	116.6	26.5						
CD 5%	**235**	**267**	**0.28**	**0.69**	**3.03**	**0.26**						
D x V CD (5%)	**NS**	**492**	**NS**	**NS**	**NS**	**NS**						

MOHANPUR

In rice crop, initiation of tillering stage among rice cultivars (Satabdi, Baishmukhi and pre-released) was found to be independent of time of planting. Date of transplanting had significant influence on occurrence of maximum tillering stage, but no difference was observed among the varieties. Delayed transplanting resulted in the delay of maximum tillering stage by 3-9 days. Irrespective of date of transplanting, Satabdi cultivar needed 48 days to reach the panicle initiation stage. The same was 63 and 47 days respectively for Baishmukhi and pre-release variety. Significant varietal and planting time interaction was noted in 50 per cent anthesis stage.

Biomass and absorbed PAR relationship

Linear relations were observed between absorbed PAR and biomass of different rice cultivars and cv. Satabdi was found to be comparatively different in radiation utilisation with a RUE value of 0.65 g/MJ followed by Baishmukhi (0.55 g/MJ) and the pre-released cultivar (0.53g/MJ) (Fig.6.2).

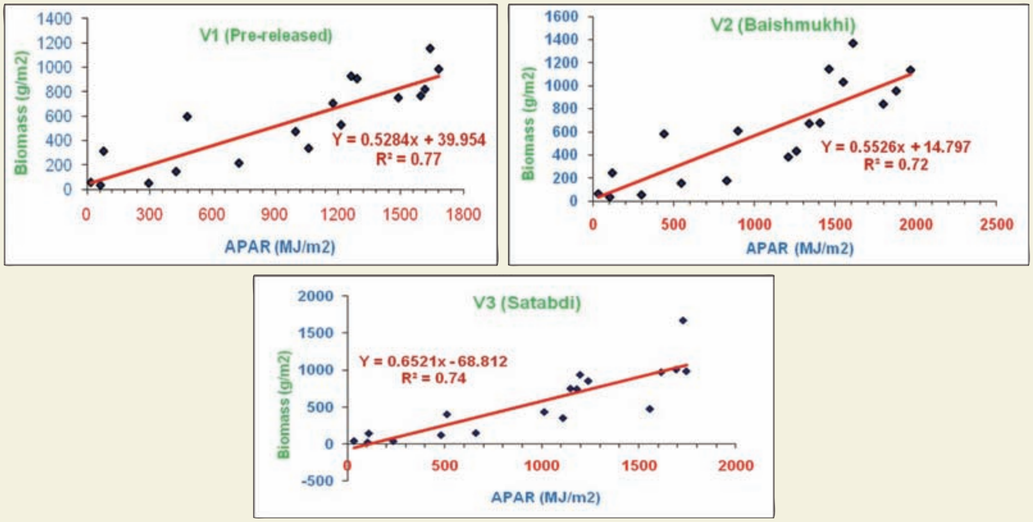


Fig.6.2. Biomass and APAR relationship of different rice cultivars at Mohanpur

RAIPUR

To study the crop-weather relationships in rice, three popular rice varieties, *viz*., Karma Mahsuri, MTU-1010 and Mahamaya were exposed to three sets of weather conditions by adopting staggered sowing dates, *viz*., 11th June, 21st June and 29th June 2010.

Heat and radiation use efficiency

Heat use efficiency (HUE) and radiation use efficiency (RUE) in respect of three varieties under three planting dates (Table 6.14) showed that HUE averaged over the varieties was highest in 21st June crop and lowest in 29th June crop while RUE was highest in late sowing (29th June) and lowest in early sowing (11th June). Among the varieties, MTU-1010 recorded highest HUE (0.50 g/m^2/°C day) while Karma Mahsuri showed highest RUE (0.84 g/m^2/MJ). These differences in HUE or RUE of different cultivars or sowing dates are not reflected in the yield achieved under those treatments.

Table 6.14. Heat and radiation use efficiency of rice varieties as influenced by different sowing dates at Raipur

Variety	HUE (g/m^2/°C day)				RUE (g/m^2/MJ)			
	11 June	21 June	29 July	Mean	11 June	21 June	29 July	Mean
Karma Mahsuri	0.47	0.49	0.40	**0.45**	0.78	0.77	0.97	**0.84**
MTU 1010	0.52	0.50	0.47	**0.50**	0.64	0.69	0.81	**0.71**
Mahamaya	0.46	0.50	0.46	**0.48**	0.74	0.74	0.84	**0.78**
Mean	**0.48**	**0.50**	**0.45**		**0.72**	**0.73**	**0.87**	

Grain yield and agroclimatic indices

Grain yield of rice varieties under varied sowing dates along with agroclimatic indices during the total growing period (Table 6.15), showed yield of all varieties to be lowest in late sown conditions. Lowest per day growing degree days and photothermal units in delayed sowing in all the varieties might be the reason for lowest yield obtained in late sowing compared to early sowing. Heliothermal units (per day), however, showed adverse effect on yield of MTU-1010 and Mahamaya.

Table 6.15. Grain yield (kg/ha) of rice along with agroclimatic indices during the growing period at Raipur

Sowing date	Variety		
	Karma Mahsuri	MTU-1010	Mahamaya
Yield			
11th June	5170	4789	4726
21st June	4870	4167	5156
29th June	3341	3163	4352
Growing degree days			
11th June	18.7	18.9	18.8
21st June	18.0	18.4	18.4
29th June	17.6	18.1	17.8
Photothermal units			
11th June	237.1	242.6	239.6
21st June	226.5	233.3	231.7
29th June	219.7	228.0	223.6
Heliothermal units			
11th June	103.4	91.1	93.0
21st June	99.4	89.7	101.0
29th June	101.8	103.4	103.5

RANCHI

Crop-weather relationships in rice were studied by subjecting three varieties of rice, *viz.*, Vandana, BVD-109 and BVD-111 to three different sowing dates, *viz.*, 24th June, 6th July and 15th July 2010.

Effect of weather on yield

Yield under different sowing dates along with weather conditions during vegetative and reproductive periods of the crop (Table 6.16) brought out that crop sown on normal date (6th July) achieved higher yield compared to early or late sown conditions due to optimum rainfall and sunshine hours during reproductive period. The late sown crop recorded lowest yield (552 kg/ha) due to meagre rainfall (19 mm) during its reproductive period.

Table 6.16. Yield of rice along with weather conditions during important phenological stages at Ranchi during Kharif 2010

Date of sowing	Yield (kg/ha)	Rainfall		Sunshine hours	
		Vegetative	Reproductive	Vegetative	Reproductive
24th June	724	398	554	456	68
6th July	898	502	313	441	97
15th July	552	753	19	405	123

SAMASTIPUR

Three varieties of rice, *viz*., Rajendra Suhasini, Rajendra Bhagwati and Rajendra Kasturi were grown under four varied micro-environments caused by four staggered sowing dates, *viz*., 31st May, 14th June, 28th June and 12th July 2010.

Effect of rainfall and temperature on yield

Yield of rice under four dates of sowing in association with weather conditions brought out that yield was influenced by rainfall and temperature during 50 per cent flowering to maturity (Table 6.17). The crop sown on 31st May recorded highest yield (4761 kg/ha) due to receipt of higher rainfall and prevalence of favourable temperature during 50 per cent flowering to maturity compared to rainfall and temperature in delayed sowing conditions. Temperature around 27°C and rainfall of 116 mm during reproductive period was found to be optimum for achieving highest grain yield in rice.

Table 6.17. Effect of rainfall and temperature on yield of rice during *kharif* 2010 at Samastipur

Date of sowing	Temperature (°C)		Rainfall (mm)	Yield (kg/ha)
	50 % Flowering to maturity	Mean temperature (°C)		
31st May	23.3-31.1	27.2	115.6	4761
14th June	24.8-33.6	24.8	46.3	4330
28th June	22.8-32.4	22.8	40.8	4042
12th July	23.4-36.3	23.4	26.3	2618

MAIZE

RAKH DHIANSAR

To study the effect of weather conditions on growth, development and yield of maize, two genotypes, *viz*., Kanchan-517 (V_1) and Hybrid-4046 (V_2) were sown on three dates, *viz*., 26th June (D_1), 6th July (D_2) and 15th July (D_3) 2010.

Radiation Use Efficiency

Radiation use efficiency of variety (Kanchan-517) and Hybrid (4640) were worked out by regressing periodic dry matter of each genotype against their periodic accumulated PAR. The RUE calculated as the slope of linear regression between dry matter and accumulated PAR (Fig.6.3) was higher in Hybrid-4640 (1.95 g/m^2/MJ) than in Kanchan-517 (1.81 g/m^2/MJ). The higher RUE in Hybrid-4640 is also reflected in its higher yield compared to Kanchan-517.

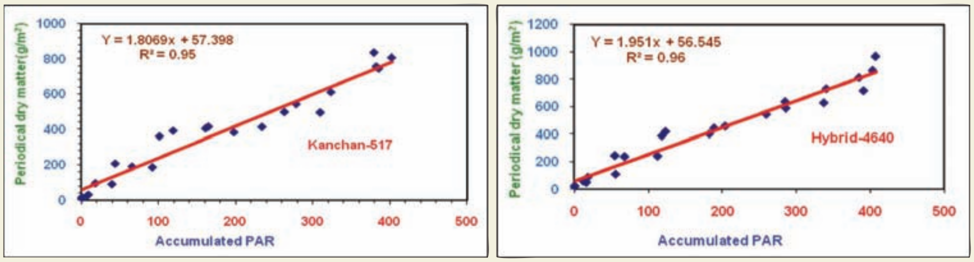


Fig.6.3. Relationship between accumulated PAR and dry matter production in Kanchan-517 and Hybrid (4640) at Rakh Dhiansar

Influence of agroclimatic indices on yield and yield attributes

Yield and yield attributes of maize under three dates of sowing and the corresponding agroclimatic indices, *viz*., per day growing degeree days (GDD), photothermal units (PTU) and heliothermal units (HTU) at Rakh Dhiansar (Table 6.18) brought out that higher yield (averaged over both varieties) in early sowing was due to higher per day GDD, PTU and HTU prevailed during total growing period than in other sowings.

Table 6.18. Yield and yield attributes of maize and associated agrometeorological indices at Rakh Dhiansar

Date of sowing	Seed yield (kg/ha)	Biological yield (kg/ha)	Cob length (cm)	Test weight (g)	Growing degree days (°C day)	Photothermal Units (hr °C day)	Heliothermal units (hr °C day)
26-06-2010	2903	9457	19.0	250.3	20.9	276.4	109.5
06-07-2010	2829	9015	15.6	234.3	20.4	265.6	108.1
15-07-2010	2155	7870	12.8	202.7	20.2	257.3	106.1

Evapotranspiration in maize

To determine weekly evapotranspiration and consumptive use of moisture during the growing period of maize, the crop was sown on 17th July 2010 (29 SMW) in both lysimeter and experimental field. Consumptive use of moisture during the entire growing period was 369 mm. Weekly evapotranspiration showed two peaks, one in third week and another major peak in 8th week of the crop (Fig.6.4). The peak evapotranspiration occurred during flowering stage of the crop.

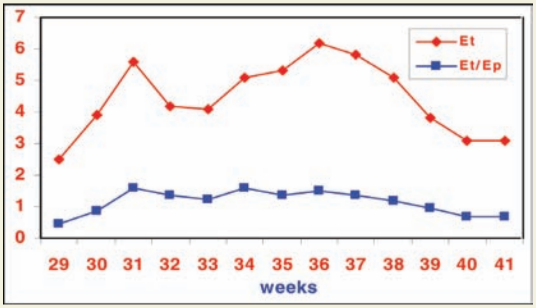


Fig.6.4. Weekly average evapotranspiration (Et) and its ratio with reference evapotranspiration (Eo)

UDAIPUR

To study the effect of weather conditions on yield of maize and also to study micro-meteorological profile of the crop, three varieties, *viz*., HQPM-1 (V_1), PEHM-2 (V_2) and Pratap-1 (V_3) were sown on three different dates – 16th June, 30th June and 15th July. In addition to these treatments, two row spacing treatments, 45 cm (R_1) and 60 cm (R_2) were also added for studying micro-meteorological profile of the crop.

Temperature profile

Temperature at different heights within each crop variety sown under three dates of sowing and row spacing (Table 6.19) revealed that in late sown crop, the temperature at heights 60 and 90 cm in 55 to 60 days crop were significantly higher in wider row spacing (60 cm) than in closer row spacing (45 cm), in all the varieties.

Relative humidity profile

Relative humidity in respect of variety HQPM-1 under three dates of sowing in closer and wider row spacing conditions (Fig.6.5) showed that higher relative humidity was recorded at all heights in closer row spacing (45 cm) compared to wider row spacing (90) under all the dates of sowing. However, the difference in relative humidity was more pronounced at 60 and 90 cm heights.

Table 6.19. Temperature (°C) profile in three maize varieties under three dates of sowing at Udaipur

Height/ varieties	Variety					
	HQPM-1		PEHM-2		Pratap-1	
	R_1	R_2	R_1	R_2	R_1	R_2
16th June 2010						
Ground	30.5	30.4	29.2	30.2	30.0	30.8
30 cm	30.8	30.6	30.4	30.4	30.5	30.0
60 cm	30.2	31.2	30.2	30.5	30.8	30.4
90 cm	30.5	30.8	30.5	30.6	30.6	31.2
30th June 2010						
Ground	31.9	32.4	32.4	32.6	32.1	32.2
30 cm	32.2	32.5	32.6	32.6	32.4	32.5
60 cm	32.4	32.9	32.8	33.4	32.6	32.6
90 cm	32.2	32.6	32.6	33.0	32.5	32.8
15th July 2010						
Ground	27.5	27.8	27.2	27.5	27.9	27.4
30 cm	27.5	28.2	27.4	27.5	28.0	28.2
60 cm	27.8	28.9	27.5	28.9	27.8	28.6
90 cm	27.7	29.6	27.3	28.1	27.9	28.8

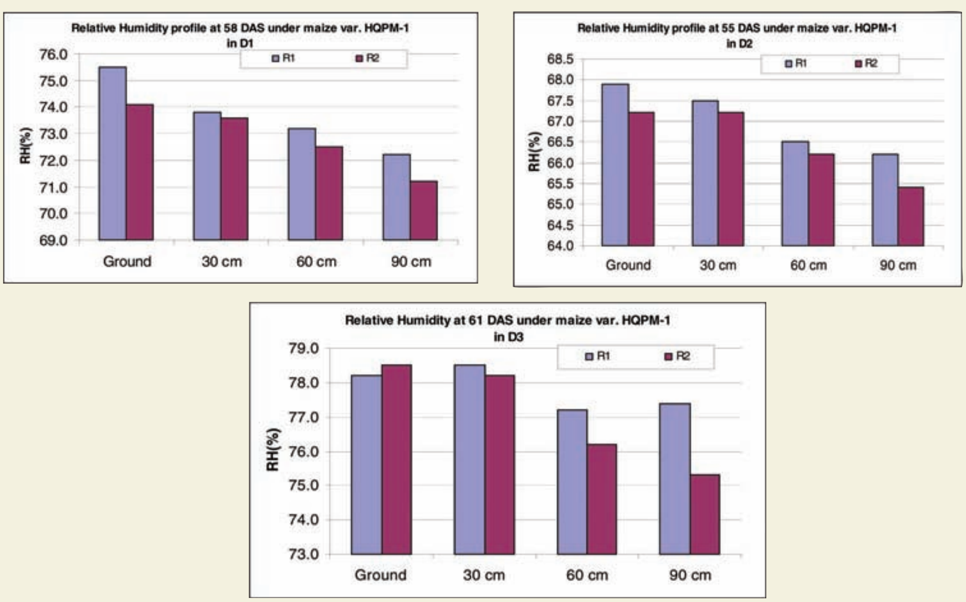


Fig.6.5. Relative humidity profile in wider and closer row spacing of maize variety HQPM under three dates of sowing at Udaipur

Effect of rainfall on yield and yield attributes

Rainfall during reproductive period, i.e., tasseling to maturity of maize showed positive influence on both yield and yield attributes (Table 6.20). Yield and yield attributes were higher in early sown crop experiencing high rainfall during its reproductive period than in late sown crop with less rainfall during reproductive period.

Table 6.20. Yield and yield attributes of maize and rainfall during reproductive period of maize during 2010 at Udaipur

Date of sowing	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest Index	No. of grains/cob	Test weight (g)	Rainfall (mm)
16th June	3982	4854	44.0	410	210.3	325
30th June	3341	4575	38.5	400	196.4	213
15th July	2392	4565	32.2	369	171.4	173

SORGHUM

PARBHANI

To assess the effects of weather on grain and fodder yield and to identify the critical weather parameters and phenological stages, two crop cultivars SPV-1567 and CSH-14 were exposed to four different weather conditions by sowing them on four dates, *viz*., 14th June, 28th June, 12th July and 26th July 2010. Grain and fodder yield of sorghum under four sowing dates in the year 2010 were correlated with weather parameters during different phenological stages of the crop (Table 6.21). The results showed that only rainfall during milk stage could influence the grain and fodder yield of sorghum significantly. Rainy days and relative humidity (morning, afternoon and mean) during flowering and milking stages had significant positive relationship with both grain and fodder yield. The temperature range during flowering and milking stages, however, showed significant inverse relationship with both grain and fodder yield.

Table 6.21. Correlation coefficients of weather variables with grain and fodder yield at Parbhani

Weather variables	Yield (kg/ha)									
	Boot stage		Flowering stage		Milk stage		Dough stage		Maturity	
	Grain	Fodder	Grain	Fodder	Grain	Fodder	Grain	Fodder	Grain	Fodder
RF	-0.01	0.08	0.55	0.57	0.92**	0.97**	0.61	0.53	0.07	0.09
RD	-0.78**	-0.74**	0.84**	0.82**	0.68*	0.72**	0.41	0.34	0.04	0.22
T_{Max}	0.41	0.35	-0.12	-0.36	-0.77**	-0.78**	0.13	0.19	0.73	0.85
T_{Min}	-0.83**	-0.87**	0.89**	0.80**	0.58	0.56	0.68*	0.74*	0.64*	0.72*
T_{Mean}	-0.45	-0.61	0.42	0.21	-0.51	-0.53	0.55	0.63	0.75**	0.86**
T_{Range}	0.66*	0.64	-0.75**	-0.89**	-0.86**	-0.86**	-0.44	-0.44	-0.04	-0.01
RHI	-0.91**	-0.95**	0.75**	0.73**	0.78**	0.73**	0.46	0.43	-0.02	-0.15
RHII	-0.77**	-0.78**	0.84**	0.92**	0.81**	0.81**	0.48	0.44	0.04	0.11
RH_{Mean}	-0.85**	-0.87**	0.83**	0.85**	0.82**	0.80**	0.49	0.45	-0.01	0.11
BSS	-0.83**	-0.92**	-0.69*	-0.84*	-0.71**	-0.58**	-0.06	-0.18	0.15	0.13

(* Significant at 5 % level ** Significant at 1 % level)

PEARLMILLET

SOLAPUR

For studying crop-weather relationships in pearlmillet, three varieties, *viz.*, Shanti, ICTP-8203 and Mahyco hybrid were exposed to three different set of weather conditions by sowing the crop varieties on 25th June, 28th July and 16th Aug 2010, respectively.

Water use and yield

The consumptive use of moisture (Cu) during entire growing period of the crop showed significant curvilinear relationship with grain yield (Fig.6.6). The cumulative moisture use of 320 mm during total growing period of the crop was found to be optimum for achieving higher grain yield and any increase or decrease in moisture use over this optimum amount reduced the grain yield.

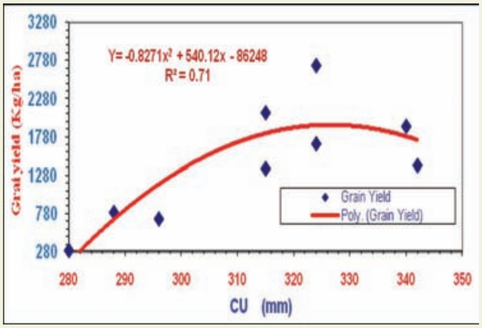


Fig.6.6. Relationship between grain yield and Cu in pearlmillet at Solapur

Heliothermal units and grain yield

Cumulative heliothermal units till physiological maturity in respect of all varieties and sowing dates showed highly significant positive relationship with grain yield (Fig.6.7).

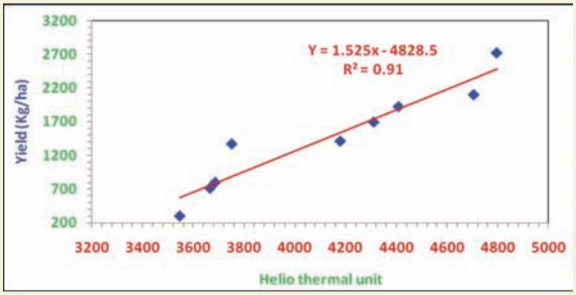


Fig.6.7. Influenec of HTU on yield of pearlmillet at Solapur

FINGERMILLET

RANICHAURI

To study the effect of temperature and moisture stresses on growth, development and yield of fingermillet, two varieties of crop, one local and another PRM-1 were exposed to three different thermal and moisture regimes, by sowing them on three dates, *viz*., 20th May, 31st May and 9th June 2010.

Effect of growing degree days on plant height

A power regression equation fitted between plant height and growing degree days (Fig.6.8) showed that plant height is positively and significantly related with growing degrees during respective phenological periods. The actual evapotranspiration also showed similar type of positive and significant relationship with plant height (Fig.6.9). The total drymatter, however, exhibited significant positive exponential relationship with growing degree days (Fig.6.10).

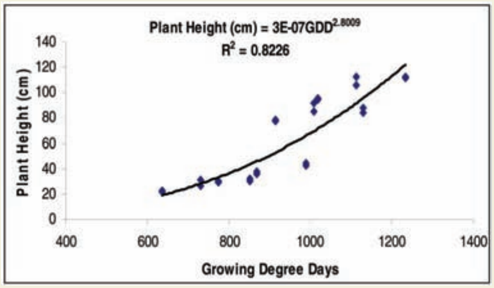


Fig.6.8. Relationship between plant height and GDD

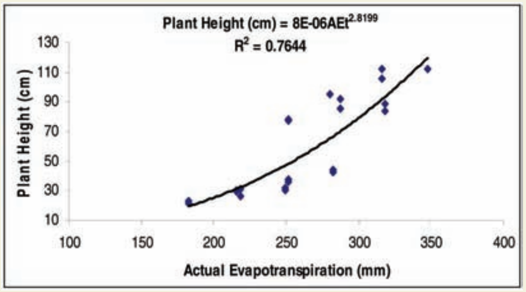


Fig.6.9. Relationship between plant height and AET

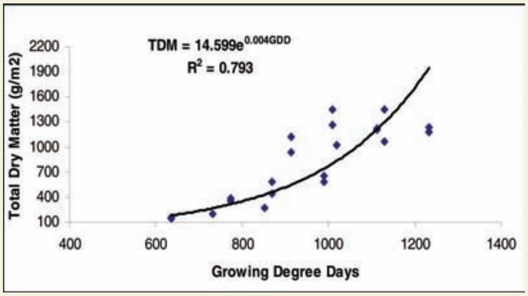


Fig.6.10. Relationship between TDM and GDD at Ranichauri

7. CROP GROWTH MODELLING

SOYBEAN

AKOLA

Phenology and growing degree days

Duration of phenological stages and accumulated growing degree days of individual phenological stages as well as the total growing period (Table 7.1) in respect of three varieties, *viz*., JS-335, TAMS-38 and TAMS-98-21 under sowing dates, 1st, 8th, 15th and 22nd July 2010 showed that except in TAMS-38, in all other varieties number of days taken and accumulated heat units required for maturity were higher under early sowing and decreased with successive delay in sowing. The accumulated growing degree days were reasonably higher during reproductive stage as compared to vegetative stage. Among the cultivars, highest number of growing degree days were accumulated by TAMS-98-21 followed by JS-335 and TAMS-38.

Table 7.1. Mean duration of phenological stages (days) and corresponding accumulated growing degree days in soybean cultivars under different sowing dates at Akola

Phenophase	JS-335	TAMS-38	TAMS-98-21
D_1- 26 MW (01.07.2010)			
Emergence	139.9(08)	139.9(08)	139.9(08)
Vegetative stage	536.3(31)	536.3(31)	603.7(35)
Flowering	220.1(13)	204.6(12)	241.3(14)
Pod formation	241.8(14)	223.1(13)	233.0(14)
Seed formation	217.7 (13)	216.4(13)	248.7(14)
Full seed development	272.2 (15)	236.8(13)	270.6(15)
Maturity	109.1(06)	108.3(06)	129.0(07)
Sowing to maturity	1737.1(100)	1665.4(96)	1866.2(107)
D_2 - 27 MW (08.07.2010)			
Emergence	146.0(08)	146.0(08)	146.0(08)
Vegetative stage	524.5(31)	524.5(31)	557.4 (33)
Flowering	225.0(13)	207.5(12)	227.4 (13)
Pod formation	198.5(12)	200.4(12)	212.3 (13)
Seed formation	229.5(13)	207.7(12)	253.4 (14)
Full seed development	272.2(15)	255.3(14)	272.3(15)
Maturity	110.5(06)	127.4(07)	128.5(07)
Sowing to maturity	1706.2(98)	1668.8(96)	1797.3(103)

Phenophase	JS-335	TAMS-38	TAMS-98-21
D_3 - 28 MW (15.07.2010)			
Emergence	151.1(08)	151.1(08)	151.1(08)
Vegetative stage	493.7(30)	478.2(29)	528.5(32)
Flowering	224.6(13)	205.8(12)	223.3(13)
Pod formation	199.3(12)	180.4(11)	219.2(13)
Seed formation	236.8(13)	218.1(12)	237.0(13)
Full seed development	254.4(14)	252.1(14)	274.9(15)
Maturity	109.8(06)	111.0(06)	102.7(06)
Sowing to maturity	1669.7(96)	1596.7(92)	1736.7(100)
D_4 - 29 MW (22.07.2010)			
Emergence	153.9(09)	153.9(09)	153.9(09)
Vegetative stage	463.6(28)	446.6(27)	498.6(30)
Flowering	200.4(12)	202.1(12)	196.7(12)
Pod formation	189.6(11)	186.6(11)	213.8(12)
Seed formation	236.1(13)	220.1(12)	236.2(13)
Full seed development	238.1(13)	217.7(12)	237.6(13)
Maturity	87.7(05)	92.6(05)	115.9(07)
Sowing to maturity	1569.4(91)	1519.6(88)	1652.7(96)

(Figures in the parenthesis are duration of Phenological stages)

JABALPUR

Growing degree days

Number of days and cumulative degree days required for occurrence of phenological stages in three varieties, *viz.*, JS-335, JS-93-05 and JS-97-52 under three dates of sowing (Table 7.2) showed that more number of days and higher degree days were required for occurrence of phenological stages upto pod initiation in late sown crop compared to early sowing conditions. However, degree days requirement for physiological maturity and harvest maturity did not vary much in different varieties and in different dates of sowing.

Table 7.2. Days taken and growing degree days required for occurrence of different phenological stages of soybean during 2010 at Jabalpur

Phenological stage	Date of sowing	Varieties		
		JS-335	JS-93-05	JS-97-52
Emergence	1st July	117(6)	99(5)	99(5)
	15th July	115(6)	115(6)	115(6)
	30th July	139(8)	156(9)	156(9)
Flower initiation	1st July	663(42)	853(47)	835(46)
	15th July	752(42)	845(47)	845(47)
	30th July	840(47)	957(54)	911(51)

Phenological stage	Date of sowing	Varieties		
		JS-335	JS-93-05	JS-97-52
Pod initiation	1st July	998(55)	1053(58)	1035(57)
	15th July	1045(58)	1151(64)	1151(64)
	30th July	1089(62)	1203(69)	1187(68)
Physiological maturity	1st July	1564(87)	1613(90)	1660(93)
	15th July	1560(89)	1671(96)	1671(96)
	30th July	1631(98)	1545(91)	1558(92)
Harvest	1st July	1711(96)	1760(99)	1808(102)
	15th July	1702(98)	1834(107)	1834(107)
	30th July	1771(108)	1859(114)	1802(110)

(*Values in parenthesis are days taken)

GROUNDNUT

ANANTAPUR

The number of days taken as well as the accumulated growing degree days (AGDD) and heliothermal units (HTU) for occurrence of different phenological stages under three different micro-environments, i.e., dates of sowing – 8th July, 24th July and 8th August 2010 (Table7.3) showed that the number of days taken and degree days requirement for physiological maturity were highest (124 days and 2178°C days) in early sown crop and they decrease with each delay in sowing. The HTU from sowing to maturity, however, did not differ significantly under different sowing dates. The crop sown on normal date (24th July) required highest accumulated GDD (470°C day) and HTU (2287°C hr) to attain 50 per cent flowering compared to early and late sown crop.

Verification of phenology predicting models

Using data on duration of phenological stages and corresponding degree days in groundnut, three regression models were developed for predicting number of days required for occurrence of flowering, pod initiation and maturity stages. These models were validated by comparing simulated and observed phenological events under three dates of sowing in the year 2010 (Table 7.4). These models could predict the flowering and pod initiation stages accurately with an error of one day only under all three dates of sowing. However, models failed to predict maturity stage accurately under all the dates of sowing.

Table 7.3. Days taken from sowing to each phenological stage of groundnut and the corresponding accumulated GDD and HTU at Anantapur

Phenophase	DAS	AGDD	AHTU
D_1: 08.07.2010			
Emergence	8	148	504
50% Flowering	25	462	1446
Pegging	36	669	2716
Pod initiation	48	881	3649
Physiological maturity	124	2178	10147
D_2: 24.07.2010			
Emergence	7	120	282
50% Flowering	26	470	2287
Pegging	37	654	2952
Pod initiation	49	855	3527
Physiological maturity	119	2049	10159
D_3: 08.08.2010			
Emergence	8	132	80
50% Flowering	27	456	2125
Pegging	38	643	2664
Pod initiation	46	780	3002
Physiological maturity	116	1952	10146

Table 7.4. Comparison of actual and predicted phenological events of groundnut under three dates of sowing in *kharif* 2010 at Anantapur

Phenological event	Prediction equation	Number of days	
		Predicted	Actual
Early sowing (07.07.2010)			
Flowering	$Y= 0.0604 X – 2.3$	25	25
Pod initiation	$Y = 0.0526 X + 3.5$	50	49
Maturity	$Y = 0.0353 X + 39.7$	117	126
Normal sowing (23.07.2010)			
Flowering	$Y = 0.0604 X – 2.3$	29	28
Pod initiation	$Y = 0.0526 X + 3.5$	49	50
Maturity	$Y = 0.0353 X + 39.7$	113	121
Late sowing (07.08.2010)			
Flowering	$Y = 0.0479 X + 3.2$	26	27
Pod initiation	$Y = 0.0495 X + 5.7$	46	47
Maturity	$Y = 0.0237 X + 59.2$	104	110

(Variable X = Growing Degree Days)

COTTON

AKOLA

Phenology and growing degree days

Duration and growing degree days requirement of different phenological stages of Bt cotton cultivar Ankur-651 under three sowing dates and four adaptation strategies (Table 7.5) revealed that both number of days taken and growing degree days required from sowing to last picking were higher in early sown crop (182 days and 2269°C day) and reduced with delay in sowing. The adaptation strategies, however, failed to influence the duration and degree days requirement of crop. The duration of the stage from sowing to emergence was prolonged and took 13 days under early sowing (dry sowing) due to lack of rains compared to other sowing conditions which took 5 to 7 days.

Table 7.5. Mean duration and accumulated GDD (^{0}C day) for various phenophases of cotton under different sowing dates and adaptation strategies at Akola

Phenophase	Adaptation strategy				Mean
	Conven-tional practice	Conser-vation furrows	Dead mulch	Live mulch	
D_1 – Dry sowing (08.06.2010)					
Sowing to emergence	230(13)	230(13)	230 (13)	230(13)	230(13)
Emergence to first square	421(30)	436(31)	436(31)	405(29)	424(30)
First square to first flower	210(18)	208(18)	195(17)	181(15)	197(17)
First flower to first boll burst	568(47)	586(48)	581(48)	543(45)	570(47)
First boll burst to first picking	157(12)	169(13)	157(12)	147(11)	158(12)
First picking to last picking	681(62)	685(65)	696(65)	699(61)	690(63)
Emergence to last picking	2036(169)	2078(175)	2064(173)	1976(161)	2038(169)
Sowing to last picking	2266(182)	2308(188)	2294(186)	2207(174)	2269(182)
D_2 – Monsoon sowing (24.06.2010)					
Sowing to emergence	114(07)	114(07)	114(07)	114(07)	114(07)
Emergence to first square	465(37)	474(38)	465(37)	454(37)	465(37)
First square to first flower	171(15)	187(16)	171(15)	160(14)	172(15)
First flower to first boll burst	549(44)	563(45)	562(45)	549(44)	556(45)
First boll burst to first picking	146(11)	159(12)	147(11)	133(10)	146(11)
First picking to last picking	591(58)	555 (60)	584(59)	582(56)	578(58)
Emergence to last picking	1922(165)	1938(171)	1930(167)	1878(161)	1917(166)
Sowing to last picking	2035(172)	2052(178)	2043(174)	1992(168)	2031(173)
D_3 – Late sowing (09.07.2010)					
Sowing to emergence	68(05)	68 (05)	68(05)	68(05)	68(05)
Emergence to first square	408(34)	419(35)	408(34)	408(34)	411(34)
First square to first flower	173(14)	184(15)	173(14)	161(13)	173(14)

Phenophase	Adaptation strategy				
	Conventional practice	Conservation furrows	Dead mulch	Live mulch	Mean
First flower to first boll burst	500(40)	534(41)	514(41)	475(38)	506(40)
First boll burst to first picking	169(13)	170(14)	165(13)	172(13)	169(13)
First picking to last picking	512(53)	470(55)	505(54)	508(50)	499(53)
Emergence to last picking	1761(154)	1777(160)	1766(156)	1723(148)	1757(154)
Sowing to last picking	1830(159)	1845(165)	1835(161)	1792(153)	1825(159)
Mean					
Sowing to emergence	137(08)	137(08)	137(08)	137(08)	137(08)
Emergence to first square	431(34)	443(35)	436(34)	423(33)	433(34)
First square to first flower	185(16)	191(16)	180(15)	167(14)	181(15)
First flower to first boll burst	539(44)	561(45)	553(45)	522(42)	544(44)
First boll burst to first picking	157(12)	166(13)	156(12)	151(11)	158(12)
First picking to last picking	594(58)	570(60)	595(59)	597(56)	589(58)
Emergence to last picking	1906(163)	1931(169)	1920(165)	1859(157)	1904(163)
Sowing to last picking	2044(171)	2068(177)	2057(173)	1997(165)	2042(171)

(Figures in parentheses are number of days)

MAIZE

RAKH DHIANSAR

To validate Campbell and Diaz Model for maize, the periodic (every 10 days) dry matter production observed in the ongoing experiment of crop-weather relations in maize were used. In this experiment, two genotypes, *viz.*, Kanchan-517 and Hybrid 4046 were sown on three different dates, i.e., 26th June, 6th July and 15th July 2010, respectively. The soil moisture contents at field capacity, permanent wilting point and air dryness required for running the model were assumed to be 0.25, 0.08 and 0.02, respectively. The crop related inputs, *viz.*, maximum rooting depth, initial biomass and extinction coefficient were taken as 1.5 meters, 0.06 gm and 0.7, respectively. The 1:1 regression equation between observed and simulated dry matter production at different intervals (Fig.7.1) in respect of all three sowing dates brought out that the model perfectly simulated (R^2 > 0.94) dry matter production (averaged over varieties) in all the three dates of sowing.

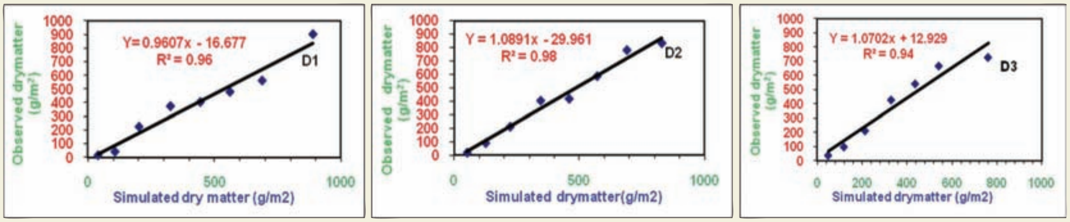


Fig.7.1. Observed and simulated dry matter production (g/m²) in maize crop at Rakh Dhiansar

UDAIPUR

Growing degree days

Number of days taken and accumulated growing degree days required for occurrence of different phenological stages in respect of three varieties HQPM-1, PEHM-2 and Pratap-1 under varied environments or dates of sowing, *viz.*, 16th June, 30th June and 15th July 2010 (Table 7.6) revealed that the growing degree days requirement and number of days taken for attaining maturity to be higher in early sowing compared to late sowing, in all the varieties. However, the difference in degree days requirement and duration of crop till maturity between early and late sowings were more significant in variety HQPM-1 only (1755°C day in early and 1388°C days in late sowings). Among the varieties, HQPM-1 took more number of days and required more growing degree days compared to other varieties for attaining phenological stages beyond knee height stage, under early sowing conditions.

Table 7.6. Accumulated growing degree days (GDD) and days taken for different growth stages of maize varieties during 2010 at Udaipur

Varieties/ Sowing dates	Emer-gence	5th Leaf	Knee height	Tass-eling	Silking	Milking	Dough	Maturity
HQPM-1								
16th June	86(4)	292(13)	848(43)	1032(54)	1082(57)	1377(74)	1611(88)	1755(97)
30th June	83(4)	264(14)	647(36)	886(50)	953(54)	1210(69)	1447(84)	1523(89)
15th July	96(5)	233(13)	604(35)	814(47)	895(52)	1141(67)	1322(79)	1388(83)
PEHM-2								
16th June	86(4)	292(13)	676(33)	864(44)	982(51)	1221(65)	1478(80)	1562(85)
30th June	83(4)	264(14)	631(35)	833(47)	902(51)	1193(68)	1387(80)	1461(85)
15th July	96(5)	233(13)	604(35)	778(45)	863(50)	1141(67)	1322(79)	1388(83)
Pratap-1								
16th June	86(4)	292(13)	676(33)	864(44)	934(48)	1185(63)	1413(76)	1478(80)
30th June	83(4)	264(14)	547(30)	782(44)	850(48)	1111(63)	1308(75)	1371(79)
15th July	96(5)	233(13)	586(34)	689(40)	742(43)	1044(61)	1322(79)	1388(83)

(* Figures in parenthesis are days)

RICE

FAIZABAD

DSSAT model was used for crop growth modelling in rice and the model is over-estimating the rice yields. The errors in estimation increased with delay in sowing (Table 7.7). Rice yields simulated with CERES rice were in close agreement with observed yields for July 5th planting date (+3%) and the model over estimated for delayed sowings.

Table 7.7. Comparison of observed and simulated rice yields (kg/ha) at Faizabad during 2010

Date of transplanting	Simulated	Observed	% error
5th July	4271	4110	3.7
15th July	3624	3460	4.5
25th July	3599	3290	8.0

HISAR

Using CERES-Rice model, impact of climatic changes on rice yield (cv B-370) were simulated for Ambala and Karnal stations for the period of 1977 to 2008. Model overestimated grain yield for both locations, but the variability of the predicted values for Ambala and Karnal falls within accepted levels (Fig.7.2 a & b).

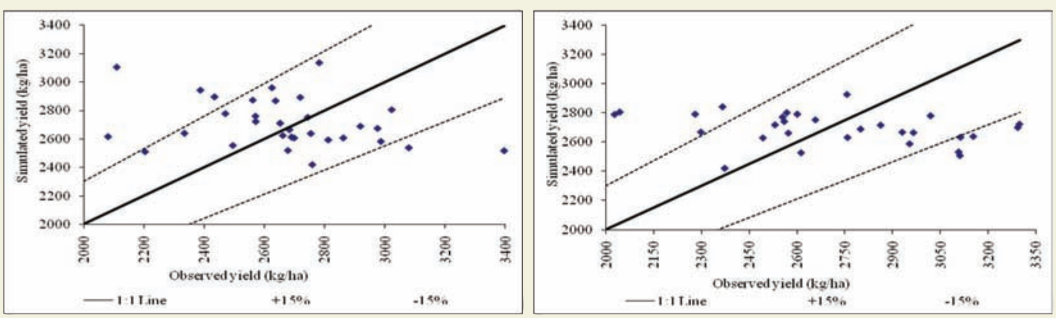


Fig.7.2a & b. Observed and simulated grain yield (kg/ha) at Ambala and Karnal during 1977-2008

An increase in maximum temperature of up to 1ºC above normal resulted in positive effect on rice productivity at both locations (Table 7.8). However, the increment of minimum temperature by 0.5ºC led to its reduction. Further, the model projected a decrease of 19.0 and 16.9 per cent in rice grain yield with increase of both maximum and minimum temperatures by 2.5°C above normal at Ambala and Karnal, respectively. The increase of either maximum or minimum temperature (up to 1°C) in conjunction with increment of CO_2 concentration in atmosphere (up to 100 ppm) resulted in increase of rice productivity at both the locations. The interaction studies suggested that the negative effect of incremental temperatures on rice productivity were marginalized with progressive increments of CO_2 concentrations.

Table 7.8. Predicted variability in rice productivity (%) with different interaction effects of temperature and carbon dioxide at Hisar

Temperature variations from present-day	Increased CO_2 concentration from normal (330ppm)					
	50ppm	60ppm	70ppm	80ppm	90ppm	100ppm
Actual Maximum + T_{Min}	4.61	5.49	6.40	7.34	8.28	9.22
+ 1ºC T_{Max}	0.61	1.52	2.40	3.30	4.19	5.12
+2ºC T_{Max}	-3.72	-2.91	-2.06	-1.22	-0.62	0.61
+3ºC T_{Max}	-7.31	-6.54	-5.89	-5.04	-3.61	-3.36
+4ºC T_{Max}	-12.49	-11.62	-10.78	-9.95	-9.22	-8.59
+1ºC T_{Min}	0.98	1.80	2.70	3.56	4.47	5.38
+2ºC T_{Min}	-2.61	-1.78	-0.92	-0.05	0.83	1.71
+2.5ºC T_{Min}	-4.65	-3.80	-3.01	-2.19	-1.33	-0.47
+1ºC T_{Max} +1ºC T_{Min}	-3.18	-2.35	-1.47	-0.56	0.32	1.19
+2ºC T_{Max} +2ºC T_{Min}	-10.66	-9.99	-9.25	-8.48	-7.60	-6.81
+1.5ºC T_{Max} +2.5ºC T_{Min}	-10.41	-9.59	-8.77	-7.95	-7.12	-6.34
+3ºC T_{Max} +1ºC T_{Min}	-11.67	-10.81	-9.99	-9.12	-8.26	-7.49

KANPUR

The cumulative heat unit requirement for different phenological stages of rice varieties NDR-359, CSR-27 and Sarjoo-52 under early (16th July), normal (26th July) and late (5th Aug) sowing conditions (Table 7.9) revealed that early sown crop required 76 higher heat units for attaining all phenological stages compared to the delayed sowing conditions. The variation in heat unit requirement of different varieties is not significant.

Table 7.9. Cumulative heat unit requirement for different phenophases of three rice varieties under three dates of sowing during 2010 at Kanpur

Sowing date	Variety	Phenophases			
		Transplanting	Tillering	Vegetative	Reproductive
16th July	NDR-359	555	1281	1887	2600
	CSR-27	555	1193	1735	2520
	Sarjoo-52	555	1237	1845	2560
	Mean	**555**	**1237**	**1822**	**2560**
26th July	NDR-359	522	1222	1797	2437
	CSR-27	555	1136	1657	2389
	Sarjoo-52	522	1200	1756	2407
	Mean	**533**	**1186**	**1737**	**2411**
5th Aug	NDR-359	501	1204	1699	2315
	CSR-27	501	1161	1579	2230
	Sarjoo-52	501	1203	1660	2258
	Mean	501	1190	1646	2268

LUDHIANA

Crop phenology

The phenological calendar of rice cultivars PR-116 and PR-118 under five dates of transplanting are presented in Table 7.10 and 7.11, respectively. Amongst the cultivars PR-116 completed its phenological development early followed by PR-118. The data indicated that the early transplanted rice crop matures at a faster rate than late transplanted crop.

Table 7.10. Phenological calendar of rice cultivar PR-116 under different dates of sowing during 2010 at Ludhiana

Phenological events	D_1 (11th June)	D_2 (18th June)	D_3 (25th June)	D_4 (2nd July)	D_5 (9th July)
Transplanting	30(30)	30(30)	30(30)	30(30)	30(30)
Maximum Tillering	47(77)	44(74)	41(71)	48(78)	45(75)
Booting	19(96)	18(92)	19(90)	18(96)	19(94)
Panicle initiation	9(105)	7(99)	13(103)	9(105)	9(103)
Heading	4(109)	6(105)	5(108)	4(109)	5(108)
Grain filling	18(127)	20(125)	17(125)	15(124)	12(120)
Physiological maturity	12(139)	9(134)	8(133)	7(131)	9(129)

(Figures in parentheses are days after sowing)

Table 7.11. Phenological calendar of rice cultivar PR-118 under different dates of sowing during 2010 at Ludhiana

Phenological events	D_1 (11th June)	D_2 (18th June)	D_3 (25th June)	D_4 (2nd July)	D_5- (9th July)
Transplanting	30(30)	30(30)	30(30)	30(30)	30(30)
Maximum Tillering	47(77)	44(74)	42(72)	50(80)	46(76)
Booting	22(99)	20(94)	21(93)	17(97)	18(94)
Panicle initiation	8(107)	8(102)	11(104)	11(108)	11(105)
Heading	4(111)	5(107)	6(110)	4(112)	4(109)
Grain filling	19(130)	20(127)	17(127)	14(126)	15(124)
Physiological maturity	15(145)	14(141)	10(137)	17(143)	13(137)

(Figures in parentheses are days after transplanting)

Heat units accrued

Growing-degree days (GDD) requirement to attain various crop growth stages indicated early transplanted rice cultivar accrued more heat units to attain physiological maturity as compared to late sown rice cultivars (Table 7.12). Heliothermal units (HTU) required to attain different growth stages of crop are shown in Table 7.13.

Table 7.12. Growing-degree days (GDD) accrued by rice cultivars under different dates of sowing, *Kharif* 2010 at Ludhiana

Phenological events	11th June (D_1)	18th June (D_2)	25th June (D_3)	2nd July (D_4)	9th July (D_5)
PR-116					
Sowing-Transplanting	684(684)	682(682)	695(695)	665(665)	658(658)
Transplanting - Maximum Tillering	1019(1703)	944(1626)	850(1545)	978(1643)	922(1580)
Maximum Tillering- Booting	385(2088)	365(1991)	377(1922)	351(1994)	368(1948)
Booting - Panicle initiation	369(2457)	133(2124)	256(2178)	161(2155)	147(2095)
Panicle initiation - Heading	77(2534)	119(2243	94(2272)	66(2221)	83(2178)
Heading - Grain filling	338(2872)	358(2601)	280(2552)	251(2471)	205(2383)
Grain filling - Physiological maturity	196(3068)	150(2751)	138(2690)	122(2593)	151(2534)
PR-118					
Sowing-Transplanting	684(684)	682(682)	695(695)	665(665)	658(658)
Transplanting - Maximum Tillering	1019(1703)	944(1626)	869(1564)	1018(1683)	940(1598)
Maximum Tillering- Booting	444(2147)	405(2031)	416(1980)	332(2015)	350(1948)
Booting - Panicle initiation	153(2300)	152(2183)	218(2198)	191(2206)	179(2127)
Panicle initiation - Heading	78(2378)	102(2285)	107(2305)	62(2268)	68(2195)
Heading - Grain filling	347(2725)	347(2632)	282(2587)	239(2507)	260(2455)
Grain filling - Physiological maturity	251(2976)	240(2872)	174(2761)	280(2787)	204(2659)

(Figure in parenthesis is cumulative growing degree days)

Table 7.13. Heliothermal heat units accrued by rice cultivars under different dates of sowing, *Kharif* 2010 at Ludhiana

Phenological events	11th June (D_1)	18th June (D_2)	25th June (D_3)	2nd July (D_4)	9th July (D_5)
PR-116					
Sowing-Transplanting	5933(5933)	6205(6205)	6239(6239)	5434(5434)	5003(5003)
Transplanting - Maximum Tillering	6335(12268)	5242(11447)	4718(10957)	4807(10241)	4504(9507)
Maximum Tillering- Booting	2328(14596)	1925(13372)	1422(12379)	2009(12250)	2230(11737)
Booting - Panicle initiation	6239(20835)	645(14017)	1656(14035)	903(13153)	1048(12785)
Panicle initiation - Heading	748(21583)	925(14942)	518(14553)	647(13800)	585(13370)
Heading - Grain filling	1871(23454)	2068(17010)	2138(16691)	2109(15909)	1696(15066)
Grain filling - Physiological maturity	1574(25028)	1389(18399)	1108(17799)	384(16293)	810(15876)
PR-118					
Sowing-Transplanting	5933(5933)	6205(6205)	6239(6239)	5434(5434)	5003(5003)
Transplanting - Maximum Tillering	6335(12268)	5242(11447)	4718(10957)	4921(10355)	4560(9563)
Maximum Tillering- Booting	2389(14657)	2039(13486)	1930(12887)	2021(12376)	2174(11737)
Booting - Panicle initiation	861(15518)	1107(14593)	1274(14161)	1291(13667)	1111(12848)
Panicle initiation - Heading	6071(16125)	434(15027)	524(14685)	213(13880)	686(13534)
Heading - Grain filling	2091(18216)	2155(17182)	2369(17054)	2136(16016)	1730(15264)
Grain filling - Physiological maturity	2109(20325)	2043(19225)	966(18020)	1194(17210)	1021(16285)

(Figure in parenthesis is cumulative Heat-thermal units)

MOHANPUR

Potential yields for Ratna variety were simulated using INFOCROP model with normal planting time (1st June). Under non-stressed conditions for water and nutrients, the potential yields decreased by 830 kg/ha for 1°C rise in maximum and minimum temperatures. Crop duration decreased by 2 days with 1°C rise (Table 7.14).

Table 7.14. Potential yield (in case of temperature rise by 1°C) of rice at Mohanpur

Variety	Potential yield		Maturity period	
	Normal condition	+1°C rise	Average	+1°C rise
Ratna	5190.4*	4360	109	107

(* Yield data are average of 2000 to 2008)

In case of rice, the model output shows that if older seedlings (about 25 days old) are transplanted (in case of +1^{0}C rise in temperature) the yield is further reduced. It may be due to the fact that increase in temperature hastens the physiological processes of the plant and the older seedling faces problem in tillering after transplanting operation. Moreover, the optimum sowing time was found to be end of May (Table 7.15).

Table 7.15. Yield of rice at two dates of transplanting at Mohanpur

Age of seedlings (days)	Dates of transplanting				
	23rd May	1st June	8th June	15th June	30th June
18	4712.5	4267	4347	4142.2	4331.5
25	4359.1	4098.45	3906.7	3794.75	4385.6

RANCHI

Growing degree days

The number of days taken and cumulative degree days required to attain important phenological stages of three crop varieties under three sowing dates (Table 7.16) brought out that the duration of crop from sowing to maturity has not changed much (1 to 3 days only) due to different sowing dates and varieties. The requirement of degree days for occurrence of different phenological stages also not varied significantly across different sowing dates and varieties. The varieties under three sowing dates required 1430 to 1547 degree days (°C day) from sowing to maturity.

Table 7.16. Number of days and accumulated heat unit requirement of upland rice at Ranchi during 2010

Variety/ Stages	Date of sowing					
	24th June		6th July		15th July	
	DAS	GDD	DAS	GDD	DAS	GDD
50% Flowering						
Vandana	70	1179	70	1166	66	1083
BVD-109	68	1149	67	1118	66	1083
BVD-111	70	1179	70	1166	66	1083
100% Flowering						
Vandana	73	1229	72	1197	70	1142
BVD-109	71	1195	70	1166	70	1142
BVD-111	73	1229	72	1197	70	1142
Milking						
Vandana	79	1325	81	1327	78	1255
BVD-109	77	1293	78	1282	78	1255
BVD-111	79	1325	81	1327	78	1255
Grain filling						
Vandana	86	1433	87	1410	84	1341
BVD-109	84	1404	83	1355	84	1341
BVD-111	86	1433	87	1410	84	1341
Maturity						
Vandana	94	1547	92	1481	91	1430
BVD-109	92	1520	92	1481	91	1430
BVD-111	94	1547	92	1481	91	1430

SAMASTIPUR

Phenology and thermal time requirement

The effect of sowing dates on phenology and heat unit accumulation or thermal time of rice varieties presented in Table 7.17 revealed that the days taken for various phenological stages and corresponding heat unit accumulation were significantly influenced by sowing dates. The early sown (31st May) crop has taken highest number of days (142 days) and accumulated highest number of heat units (2788°C day) to reach maturity and the number of days and heat units decreased with successive delay in sowing. Other phenological stages (except tillering) also required less number of days and accumulated heat units under delayed sowing compared to early sowing.

Table 7.17. Effect of sowing dates on phenophases and heat unit accumulation of rice varieties during 2010 at Samastipur

Treatments	Tiller initiation		Boot stage		50% ear head emergence		Milk stage		Dough stage		Maturity	
	DAS	HU	DAS	HU	DAS	HU	DAS	HU	DAS	HU	DAS	HU
Sowing dates												
31st May	47.5	955.9	89.2	1793.3	109.1	2175.7	116.5	2316.8	133.0	2622.7	142.4	2788.0
14th June	48.2	949.2	88.5	1748.6	103.9	2043.1	109.7	2156.1	121.4	2366.5	131.9	2551.3
28th June	48.8	979.8	85.7	1751.3	98.9	1941.7	104.8	2050.1	119.7	2307.0	126.9	2417.9
12th July	49.5	987.9	85.7	1676.7	96.0	1864.2	106.9	1965.9	124.1	2299.1	118.9	2280.3
CD (0.05)	0.7	14.4	0.7	14.6	1.0	18.2	0.7	13.7	0.9	15.0	0.6	8.9
Varieties												
Rajendra Suhasini	48.5	969.4	88.8	1760.0	103.2	2031.7	111.0	2151.5	123.9	2388.9	128.8	2491.2
Rajendra Bhagwati	48.2	962.6	76.9	1570.2	91.9	1816.9	98.6	1919.6	119.0	2299.2	124.1	2413.9
Rajendra Kasturi	48.8	972.7	96.2	1897.2	110.6	2169.9	118.6	2295.6	130.8	2508.2	137.1	2623.0
CD (0.05)	0.6	NS	0.6	12.6	0.8	15.8	0.6	11.9	0.7	13.0	0.5	7.4

(DAS = Days after sowing; HU = Heat Units)

Among the varieties, Rajendra Kasturi took more number of days as well as accumulated heat units for reaching all the phenological stages, followed by the variety Rajendra Bhagwati.

PEARLMILLET

SOLAPUR

Drymatter partitioning

Partitioning of drymatter into different plant parts at periodic intervals in respect of three varieties, Shanti, ICTP-8203 and Mahyco under three dates of sowing, *viz*., 25th June, 28th July and 16th Aug 2010 (Table 7.18) indicated that root is the prime contributor to the total drymatter followed by leaves at emergence stage. At physiological maturity, stem was the highest contributor and leaves were lowest contributors to the drymatter in all the varieties and sowing dates. Partitioning of drymatter to earhead started at soft dough stage and it varied between 29 to 38 per cent at physiological maturity across different varieties and sowing dates.

Table 7.18. Partitioning of drymatter (%) in three varieties of pearlmillet under three dates of sowing at Solapur

Variety	Plant parts	Phenological stage					
		Emer-gence	PI	50% flowering	Soft dough	Hard dough	Phy. maturity
25-06-2010							
Shanti	Leaves	31	32	43	30	10	3
	Stem	19	43	33	32	42	37
	Root	50	26	24	25	29	24
	Earhead	0	0	0	14	19	36
ICTP-8203	Leaves	32	24	37	23	8	3
	Stem	21	54	42	39	47	51
	Root	47	202	21	23	20	17
	Earhead	0	0	0	15	25	29
Mahyco	Leaves	29	24	33	23	7	2
	Stem	18	53	44	38	47	51
	Root	53	23	23	25	21	17
	Earhead	0	0	0	14	25	29
28-07-2010							
Shanti	Leaves	29	32	36	27	11	3
	Stem	14	40	36	34	40	35
	Root	57	28	28	26	30	25
	Earhead	0	0	0	14	20	37
ICTP-8203	Leaves	27	23	36	21	9	3
	Stem	20	59	36	42	46	47
	Root	53	18	28	20	16	15

Variety	Plant parts	Phenological stage					
		Emer-gence	PI	50% flowering	Soft dough	Hard dough	Phy. maturity
	Earhead	0	0	0	17	29	35
Mahyco	Leaves	27	24	34	24	9	2
	Stem	20	55	35	45	48	47
	Root	53	21	30	27	21	20
	Earhead	0	0	0	4	22	31
16-08-2010							
Shanti	Leaves	25	28	35	25	11	3
	Stem	17	43	37	31	41	38
	Root	58	29	28	30	30	26
	Earhead	0	0	0	14	17	33
ICTP-8203	Leaves	27	25	37	24	11	3
	Stem	20	52	39	32	47	41
	Root	53	23	25	25	21	18
	Earhead	0	0	0	19	21	38
Mahyco	Leamves	25	23	34	23	10	3
	Stem	17	54	35	30	43	38
	Root	58	22	31	31	28	23
	Earhead	0	0	0	17	20	35

FINGERMILLET

RANICHAURI

Growing degree days

Accumulated growing degree days as well as the number of days required for occurrence of different phenological stages in fingermillet under three different dates of sowing (Table 7.19) revealed that number of days from sowing to harvesting increased from 154 to 166 and growing degree days decreased from 1417 to 1296°C day under delayed sowing compared to early sowing.

Drymatter partitioning

Partitioning (%) of drymatter to various plant parts in two varieties, PRM-1 (V_1) and Local (V_2) under three dates of sowing, 20th May (D_1), 31st May (D_2) and 9th June (D_3) during *kharif* 2010 (Table 7.20) showed that partitioning of dry matter to various plant parts varies with dates of sowing. The contribution of stem to total drymatter remained high (71 to 80%) during ear emergence stage, which occurred around 90, 75 and 60 DAS in first, second and third dates of sowing, respectively. In later stages also, contribution of stem to total drymatter remained higher among other plant parts.

Table 7.19. Growing degree days and number of days required for different phenological stages in fingermillet at Ranichauri

Phenological stage	Date of sowing	Days taken	Growing degree days (°C day)
Germination	20-05-2010	24	273.9
	31-05-2010	25	279.5
	09-06-2010	29	309.5
Tillering	20-05-2010	54	586.6
	31-05-2010	58	602.1
	09-06-2010	53	545.7
Jointing	20-05-2010	62	666.7
	31-05-2010	70	731.1
	09-06-2010	67	681.6
Flowering	20-05-2010	120	1189.2
	31-05-2010	118	1134.8
	09-06-2010	114	1070.9
Harvesting	20-05-2010	154	1417.0
	31-05-2010	156	1341.0
	09-06-2010	166	1296.8

Table 7.20. Drymatter partitioning into different plant components (%) at four stages of fingermillet at Ranichauri

Date of sampling	D_1V_1	D_1V_2	D_2V_1	D_2V_2	D_3V_1	D_3V_2
10-08-2010	**60 DAS**		**45 DAS**		**30 DAS**	
Root	29	30	30	27	36	42
Stem	33	33	29	33	25	20
Leaf	38	37	41	41	38	38
25-08-2010	**75 DAS**		**60 DAS**		**45 DAS**	
Root	22	16	20	13	23	19
Stem	48	56	45	61	43	49
Leaf	30	28	35	26	34	32
10-09-2010	**90 DAS**		**75 DAS**		**60 DAS**	
Root	8	5	9	5	7	9
Stem	72	80	72	80	77	71
Leaf	16	14	17	13	14	17
Ear	4	2	2	2	2	3
25-09-2010	**105 DAS**		**90 DAS**		**75 DAS**	
Root	11	11	14	11	8	9
Stem	51	50	52	54	48	56
Leaf	24	26	22	22	29	24
Ear	14	13	12	14	14	11

8. WEATHER EFFECTS ON PESTS AND DISEASES

SOYBEAN

AKOLA

Insect pest incidence of leaf eating caterpillar (*Spodoptera litura*) and semilooper (*Thysanoplusia orichalcea*) in soybean grown under four micro-environments (caused by sowing the crop on four different weeks) were analyzed in relation to weather parameters.

Pest-weather relations

Correlations between semilooper population and weather parameters during 0, 1, 2 and 3 weeks lag periods (Table 8.1) showed significant negative correlation of semilooper with maximum and mean temperature at all the lag periods. However, evening and mean relative humidity and rainfall exhibited significant positive correlation with semilooper population. These results brought out that lower maximum and mean temperatures and higher humidity conditions are congenial for semilooper population on soybean crop.

Table 8.1. Correlations of semilooper population with weather parameters at different lag periods at Akola

Parameters	Lag phase (Week)			
	0	1	2	3
MaxT	-0.511**	-0.646**	-0.602**	-0.395**
MinT	-0.039	-0.056	0.262	0.111
MeanT	-0.498**	-0.616**	-0.487**	-0.323*
RH_I	0.255	0.565**	0.633**	0.584**
RH_{II}	0.362*	0.598**	0.613**	0.488**
RH_{mean}	0.366*	0.617**	0.637**	0.522**
Rainfall	0.340*	0.639**	0.359*	0.153
Rainy day	0.142	0.469**	0.335*	0.237
BSH	-0.156	-0.460**	-0.610**	-0.564**

In regression analysis of semilooper population with weather parameters, maximum temperature, evening and mean relative humidity were found to be having significant curvilinear relationship with semilooper population (Fig.8.1). From these curvilinear relationships, maximum temperature in the range of 30 to 31°C, evening relative humidity between 62 to 63 percent and mean relative humidity of 76 to 78 per cent were found to be congenial weather conditions for semilooper population in soybean.

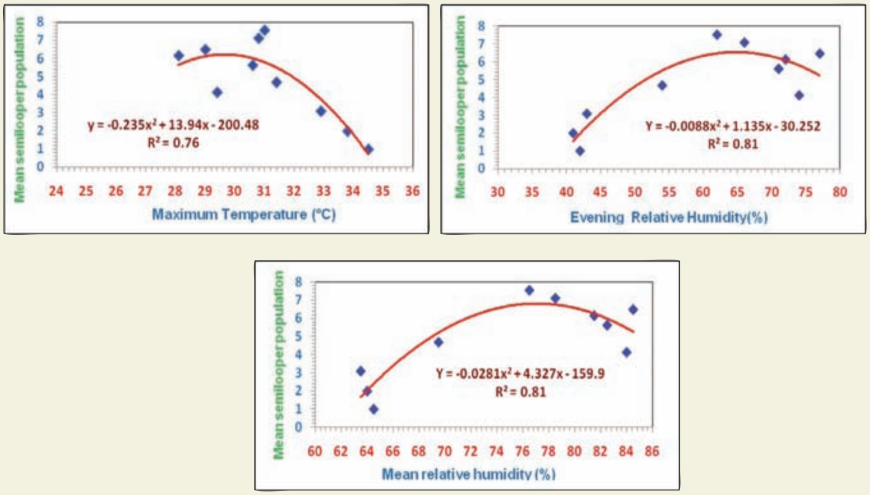


Fig.8.1. Relationship between soybean semilooper population and weather variables at Akola

GROUNDNUT

ANANTAPUR

Incidence of groundnut leaf miner (GLM) and weather

The leaf miner damage data for the past 6 years including that of 2010 and mean temperature (maximum and minimum) and relative humidity (morning and afternoon) in individual years (Table 8.2) indicated that maximum temperature less than 34.5°C and afternoon relative humidity more than 36 per cent favoured more than 10 percent GLM damage in groundnut crop.

Table 8.2. Congenial weather conditions for the incidence of groundnut leaf miner at Anantapur

Date of Sowing	Date of incidence	GLM Damage (%)	T_{Max} (^{o}C)	T_{Min} (^{o}C)	RH I (%)	RH II (%)
07.08.2003	18.09.2003	1.0	34.9	23.1	73	32
10.07.2004	06.07.2004	0.2	35.5	24.3	69	33
31.07.2006	13.08.2006	1.2	34.6	23.8	73	36
31.07.2007	22.08.2007	14.6	34.3	23.6	63	37
14.07.2008	10.08.2008	24.1	33.5	22.5	80	46
10.07.2009	21.08.2009	23.4	32.5	24.2	78	50
Mean		**10.8**	**34.2**	**23.6**	**73**	**39**

COTTON

PARBHANI

To assess the impact of different weather variables on the outbreak of bollworm in cotton, the fruiting bodies damaged due to bollworm attack (counted daily and averaged over meteorological week) were regressed with different weather parameters during the week of incidence and one week before. For this purpose, step-wise (step up) regression was used and the following regression equations brought out that standard error (SE) decreased and coefficient of determination (R^2) increased with inclusion of additional weather parameter in regression equation upto Step-5. After step-5, though R^2 increased, the standard error also increased drastically. The equations 5 and 6 with lowest and next lowest SE can be considered for prediction of bollworm damage. An interesting feature observed from the equations is that the rainfall, mean relative humidity and sunshine hours showed positive relationship while minimum temperature and morning relative humidity showed negative relationship with cotton bollworm.

Step	Régression équation	R^2	SE
Step-1	$Y = 8.339 + 0.065RF$	0.25	2.09
Step-2	$Y = 11.923 + 0.104RF - 0.243T_{Min}$	0.49	1.79
Step-3	$Y = 1.60 + 0.042RF1 + 0.111RF - 0.339T_{Min}$	0.62	1.60
Step-4	$Y = 9.16 + 0.055RF1 + 0.117RF - 0.368T_{Min} + 0.748BSS1$	0.70	1.48
Step-5	$Y = 2.81 + 0.052RF1 + 0.092RF - 0.494T_{Min} + 0.512BSS1 + 0.135\ RH_{Mean}$	0.73	1.46
Step-6	$Y = -18.75 + 0.030RF1 + 0.094RF - 0.403T_{Min} - 0.587T_{Min}1 + 0.173BSS1 + 0.179RH_{Mean}1 + 0.221RH_{Mean} - 0.070RHI$	0.77	1.75
Step-7	$Y = -37.39 + 0.026RF1 + 0.071RF - 0.720T_{Min} - 0.762T_{Min}1 + 0.137BSS1 + 0.413BSS + 0.503RH_{Mean}1 + 0.341RH_{Mean} - 0.105RHI - 0.322\ RHI1$	0.80	1.99

9. SUMMARY

The progress made by 25 Cooperating Centres of All India Coordinated Research Project on Agrometeorology in implementing the technical program of the project and salient research findings during *rabi* 2009-10 and *kharif* 2010 are summarized below.

Agroclimatic Characterization

- Long-term (40 Years) maximum and minimum temperature at Akola showed significant decreasing trend in annual and seasonal (southwest monsoon) diurnal temperature range. The reference evapotranspiration also showed significant declining trend in all four seasons and also on annual basis.
- The duration of assured weekly rainfall of 10 mm or more was longer (12 weeks) at Sindewahi of eastern Vidarbha than at Akola (5 weeks) of western Vidarbha. It was further observed that none of the weeks during the normal sowing window at Akola (24-27 SMW) received more than 10 mm weekly rainfall at 75 per cent probability, thus indicating the risk in taking up normal sowing of *kharif* crops.
- Deficit and scanty rainfall occurred in 14 years out of 43 years at Anantapur. In deficit years, start of growing season was delayed by two weeks and as a result the duration of crop season was curtailed by two weeks compared to excess or normal years.
- At Bijapur, analysis of rainfall of six districts of Karnataka brought out that start of rainy season is most delayed (27 SMW) and duration is shortest (18 weeks) at Raichur while the start is earliest (22 SMW) and duration is largest (23 weeks) at Uttar Kannada district.
- At Hisar, the average start, end and duration of rainy season were worked out to be 27 SMW, 41 SMW and 15 weeks, respectively.
- Analysis of 110 years rainfall at Jorhat revealed the declining trend in rainfall from the year 1980. During these three decades, more number of years with negative anomaly (20) were witnessed than the number of years with positive anomaly (6).
- At this centre, minimum temperature is increasing at an higher rate (0.013°C/year) and thereby resulting in decreased annual temperature range.
- At Kanpur, decadal average rainfall decreased by 101 mm from 920 mm during 1971-80 to 819 mm during 2001-2010.
- At Kovilpatti, the probability of getting rainfall of 20 mm or more is more than 50 per cent during 39 to 47 SMW only.
- Mohanpur centre reported that frequency of agricultural droughts are more in *rabi* season at both Jalpaiguri and Kalimpong stations (22 and 21 years) than in *kharif* season (10 and 13 years).

- Probability analysis at this centre further brought out that weekly rainfall of 20 mm or more with 75 per cent probability occurs during 23 to 37 SMW and 26 to 37 SMW, respectively at Jalpaiguri and Kalimpong stations.
- Analysis of long-term (1961-2009) daily temperature at Parbhani revealed that the number of events of maximum temperature > 40°C are increasing slowly (at the rate of 1 event per decade), while events with minimum temperature < 10°C are increasing at a faster rate (5 events per decade).
- At Raipur, analysis of long-term trends in annual rainfall of 17 districts of Chhattisgarh showed significant declining trend of 10.8, 5.9, 6.0 and 5.1 mm per year in Mahasamund, Raigarh, Kanker and Dhamtari districts.
- At this centre, analysis of rainfall of pre and post-global warming periods (1901-70 and 1971-2009) in all the districts of Chhattisgarh showed decreasing trend during post-global warming period compared to pre-global warming period in all the districts except Bijapur and Korba.
- At Rakh Dhiansar trend analysis of mean annual temperature and rainfall during *rabi* and *kharif* seasons at five locations of Jammu & Kashmir showed significant increase in mean annual temperature of locations Katra, Batote, Bhaderwah and Banihal only.
- Ranchi centre reported that trends in rainfall are not same across different agroclimatic zones and Dumka region of Zone-IV showed increasing trend while east Singhbhum region of Zone-VI showed decreasing trend.
- At Ranichauri, conditional probability (> 50%) of receiving wet week followed by wet week of 20 and 30 mm rainfall is confined to 25-37 and 26-37 SMW, respectively.
- Mean duration of rainy season at this centre was worked out to be 23 weeks with mean start and end of 22 and 45 SMW, respectively.
- Analysis of long-term rainfall data of two districts, *viz*., Motihari and Gaya of Bihar brought out that though onset of southwest monsoon was one week earlier (25 SMW) at Motihari than at Gaya, the duration of the season was same (17 weeks) at both the districts.
- Weekly rainfall of 20 mm or more at 75 per cent probability can be expected during 25 to 31 SMW at Motihari and 27 to 33 SMW at Gaya districts.
- Analysis of annual and seasonal rainfall of nine locations spread across north, central and southern parts of the scarcity zone of Maharashtra by Solapur centre brought out that both annual and southwest monsoon seasons' rainfall are highest at Solapur of southern part (731.8 and 550.5 mm) and lowest at Kopergaon (447.5 and 344.8 mm) of central part.

- Initial and conditional probabilities of weekly rainfall revealed that sowing of *rabi* crops only is possible in southern part of scarcity zone of Maharashtra as weekly rainfall of 20 mm or more occurs with 50 per cent or more probability during 37 to 40 SMW at four different locations of southern part.
- Drought frequency in 10 tehsils of Solapur district showed highest frequency (60%) of droughts in Sangola and lowest (42%) in Barshi and Mangalwedha tehsils.
- At Thrissur, by regressing long-term (1984-2010) reference evapotranspiration values with open pan evaporation in each season, pan coefficients for winter and summer seasons were worked out as 0.83 and 0.89, respectively.
- At Udaipur, analysis of long-term (1970-2008) rainfall in 12 districts of southeast Rajasthan showed that highest annual (1098. 2 mm) and monsoon season's rainfall (1041.7 mm) were recorded at Banswara district and lowest (542 mm annual and 496.6 mm seasonal) at Rajsamand district.
- Probability analysis of monthly rainfall in the districts of southeast Rajasthan showed that highest rainfall at 75 per cent probability can be expected in the month of July at Banswara, Bhilwara, Bundi, Kota and Pratapgarh districts and in the month of August at Baran, Chittorgarh, Dungarpur, Jhalwar and Udaipur districts.

Rabi 2009-10

Crop-Weather Relationships

Chickpea

- At Akola, maximum and mean temperature during flowering and seed development stages and minimum temperature during pod formation stage showed significant adverse effect on seed yield.
- Low maximum temperature during reproductive period favoured to achieve higher yield and more number of pods per plant at Anantapur.
- At Faizabad, crop sown on normal date (21st Oct) achieved higher radiation use efficiency (RUE) at all the stages compared to RUE under early or late sown conditions.
- At Jabalpur, higher decrease in seed yield with unit increase in minimum temperature (230.4 kg/ha) was observed than with unit increase in maximum (146.6 kg/ha) and average temperature (180.3 kg/ha). Growing degree days of 750°C day were found to be optimum for achieving higher seed yield.
- At this centre, in addition to higher temperature, longer days and more sunshine hours during reproductive period were found to be detrimental to yield of chickpea. Daily GDD, HTU and PTU of 12.3°C, 90.6°C hr and 142.1°C hr were found to be optimum for obtaining highest yield.

- At Solapur, heliothermal units (HTU), i.e., the product of degree days and sunshine hours during the growing period showed highly significant positive relationship with yield and HTU could explain 96 per cent of yield variability.

Wheat

- At Kanpur, both maximum and minimum temperature during reproductive period significantly and negatively influenced the yield. However, quantum yield reduction with unit increase in minimum temperature was higher (445.7 kg/ha) than with the increase in maximum temperature (238.1 kg/ha).
- Average maximum and minimum temperatures of 23.4 and 10.9°C, respectively during reproductive period were found to be optimum for obtaining more than 3 t/ha yield at Palampur.
- At Raipur, though duration of reproductive period showed highly significant negative relationship with maximum, minimum and average temperature during the reproductive period, the decrease in duration with unit rise in minimum temperature was higher (2.1 days) than the rise in maximum or average temperature.
- At this centre, based on thermal sensitivity index, only the variety GW-273 (out of four varieties tested) was found to be tolerant to heat stress under 30 days delayed transplanting.
- At Ranchi, not only heat and water use efficiencies, but also the yield and yield attributes were found to be higher under early sowing (20th Nov) than under 15-30 days delayed sowing, mainly due to higher soil moisture and lower maximum and minimum temperatures experienced during reproductive period of the crop.
- At this centre, yield showed highly significant negative relationship with minimum temperature during reproductive period.

  $Y = 6386.5 - 215X \quad (R^2 = 0.74)$

  From the above regression equation, it is understood that yield decreased by 215 kg/ha with 1°C increase in minimum temperature during reproductive period.
- Total drymatter showed significant curvilinear relationship with growing degree days and plant height is showing significant positive power relationship with actual evapotranspiration at Ranichauri.
- At Rakh Dhiansar, rate of interception of photosynthetically active radiation in the variety RSP-561 under irrigated condition was found to be highest and that of variety PBW-343 under rainfed condition to be lowest.

- At Samastipur, increase in daily average temperature by 2.1°C during milking to dough stage reduced the duration of this stage by 6 days. The temperature during milking to dough stage showed a parabolic relationship with yield and temperature between 24.5 and 25°C was observed to be optimum for achieving highest yield.
- Though duration of emergence, vegetative and reproductive stages were inversely related to average temperature during the respective phenological stages, the reduction in duration of reproductive stage with unit increase in temperature was more (9 days) than the duration of other phenological stages at Udaipur.
- At this centre, highest interception of PAR (95.7%) was observed in early sown crop (15^{th} Nov) with maximum five irrigations and lowest (71%) in very late sown (15^{th} Dec) crop with minimum three irrigations.
- At this same centre, average temperature of 18.2 to 18.8°C during reproductive period was observed to be optimum temperature limit for obtaining highest yield (4618 to 4665 kg/ha) and increase in temperature by 3.6°C above this optimum limit caused reduction in yield by 42.2 per cent.

Mustard

- At Hisar, seed yield and yield attributes showed significant positive correlation with maximum and minimum temperature, sunshine hours and evaporation during vegetative phase and negative relationship with same weather parameters during reproductive phase.
- Maximum temperature of 18.8°C and minimum temperature of 6°C were identified as optimum temperature limits for obtaining more than 2 t/ha yield at Palampur.
- At Udaipur, maximum, minimum and mean temperature at fortnightly intervals from sowing till 75^{th} day of crop showed positive relationship and from 76^{th} day to maturity showed negative relationship with yield.
- At this centre, increase of temperature during 90-105 days by 6.1°C in case of late sown crop compared to early sown crop resulted in reduction of yield by 1220 kg/ha.

Rabi Sorghum

- At Kovilpatti, light interception and light use efficiency in different sorghum based intercropping systems revealed higher light interception as well as utilization during flowering to pod formation stages in pulses and flowering phase in *rabi* sorghum.
- Pooled analysis of grain and fodder yields in relation to weather parameters during different phenological stages at Parbhani identified weather parameters during boot stage to be most critical than in other stages. Rainfall, minimum temperature and relative humidity during this stage showed significant positive relationship with both grain and fodder yield.

- At Solapaur, consumptive use of moisture (Cu) during total growing period showed curvilinear relationship with grain yield and Cu of 270 mm was found to be optimum for obtaining higher yield.

Sunflower

- Analysis of yield over the last five years in relation to weather parameters during vegetative and reproductive stages identified minimum temperature below 16°C during flowering stage and vapour pressure below 16 mm of Hg during flowering stage as unfavourable weather conditions for higher yield at Bijapur.

Mango

- At Dapoli, analysis of 13 years data on the number of days taken for occurrence of different phenological stages of Alphonso in relation to concurrent weather parameters brought out that the rainfall during post-monsoon (39^{th} to 40^{th} SMW) advanced the occurrence of vegetative flush. Similarly, minimum temperature during 48^{th} to 50^{th} SMW preponed the occurrence of reproductive flush.

Potato

- At Jorhat, not only accumulated temperature and sunshine hours but also the indices related to temperature and day length (growing degree days and photothermal units) during tuber formation stage adversely affected the tuber yield.
- At Mohanpur, evapotranspiration during the season (SET) showed significant positive effect on tuber yield and each one mm increase in SET resulted in 0.383 t/ha increase in tuber yield.

Maize

- At Kovilpatti, maximum temperature, minimum temperature and relative humidity in the range of 21.8-29.3°C, 17.7-23.3°C and 84-95 per cent, respectively were found to be favourable weather conditions for obtaining higher yield.

Tea

- Analysis of tea productivity over the last 15 years in relation to monthly weather parameters at Palampur brought out that fall of maximum and minimum temperature below 24.2 and 13.5°C, respectively during October reduced the tea yield drastically.

Coconut

- At Thrissur, it was observed from the analysis of leaf shedding in relation to ambient temperature, soil moisture deficit and vapour pressure deficit that peak leaf shedding occurred in April, two months after peak vapour pressure deficit noticed in February.
- At this centre, lower button shedding in June to November period was observed due to high soil moisture and low vapour pressure deficit prevailed during that period.

Crop Growth Modelling

Chickpea

- At Akola, growing degree days requirement of all three varieties from sowing to maturity were highest (1916 to 2028°C day) under early sowing and lowest (1761 to 1906°C day) when sowing was delayed by 15 days.
- Earliest sown crop (11th Oct) took more number of days (131) and growing degree days (1846°C day) for physiological maturity and they decreased with each 15 days delay in sowing till 27th Nov at Jabalpur.
- At Solapur also, early sown (24th Sept) crop varieties required higher number of degree days (1389 and 1467°C day) for maturity than under delayed sowing (1132 and 1195°C day).

Wheat

- Harvest index was influenced more by genetic variability or genotypes than environmental conditions due to varied sowing dates, as it varied from 30.6 to 38.1 per cent in three different genoptyes and from 33.4 to 36.9 per cent under three sowing dates at Kanpur.
- At Raipur, photothermal and heliothermal units of all four varieties from sowing to maturity were highest in late planting (5th Jan).
- The Campbell and Diaz model simulated dry matter production of all the four varieties of wheat, *viz*., PBW-343, RSP-560, RSP-561 and RSP-529 accurately (R^2 >0.96) at Rakh Dhiansar during *rabi* 2009-10.
- At Ranichauri, partitioning of drymatter to roots, leaves, stem and panicle were highest in tillering, jointing, anthesis and maturity stages, respectively.
- Heat units required for maturity were highest (1783.8°C day) under early sowing (25th Nov) and lowest (1592.5°C day) in late sown crop (25th Dec) at Samastipur.

Rabi Sorghum

- The percentage errors in prediction of yield and phenological events like flowering and physiological maturity using WOFOST model at Bijapur were comparatively lower in case of early sowing of crop than in late sowing at Bijapur.
- At Solapur, the degree days requirement from sowing to maturity of crop varieties was highest (1658-1963°C day) in normal sowing than in early or late sowing.

Mustard

- The early (14th Oct) crop accumulated highest number of degree days from sowing to maturity (1635.1°C day) and the late sown crop accumulated lowest number of degree days (1466.7°C day) at Hisar.

- At Ludhiana also, early sown *brassica* cultivars accrued more growing degree days (1577-1820°C day) to attain physiological maturity as compared to late sown *brassica* cultivars (1438-1616°C day)
- Validation of statistical yield prediction models showed accurate yield prediction (% error of 0.3 to 5) under early or normal sowing with two irrigations at Udaipur.
- At this centre, highest harvest index (30.2%) was achieved in early sowings (5-20th Oct) as well as with two irrigations (31%).

Weather Effects on Pests and Diseases

Safflower

- At Akola, lower maximum temperature around 27°C, minimum temperature of 7 to 8°C and highest morning relative humidity of 73 per cent were found to be congenial weather conditions for aphids population on safflower.

Mustard

- At Anand, analysis of six years pest/disease data on stem rot, rust and sawfly in relation to weather parameters in different phenological stages of the crop revealed that out of all the three pests, sawfly is more significantly influenced by weather parameters with minimum standard error of estimate (0.15 to 0.33).
- At this centre, low relative humidity during vegetative period favoured higher sawfly population in mustard.
- At Udaipur, though aphids population negatively related with maximum, minimum and mean temperature in all sowing dates, the mean temperature is more significantly related with aphid population.

Kharif 2010

Soybean

- At Akola, rainfall and minimum temperature during pod formation to full seed development showed highly significant positive relation with yield while maximum and mean temperature during seed formation to full seed development showed significant negative relationship with yield.
- At this centre, higher water use and accumulated growing degree days during the total growing period, higher rainfall during the reproductive period and higher interception of radiation during flowering to pod formation favoured to obtain higher yield and attributes in early sown crop than in late sown crop.

- At Jabalpur, all the varieties sown on early date (1st July) could register higher yield as well as yield attributes than in late sowing due to higher photothermal units, growing degree days and rainfall during reproductive period.
- Rainfall and soil moisture content during pod formation stage had highly significant positive relationship with yield at Parbhani.

Cotton

- At Akola, rainfall and rainy days at all the phenological stages except first boll burst to first picking showed highly significant positive relationship with cotton seed yield.
- Rainfall and rainy days during boll formation to first picking positively and significantly influenced the seed yield at Parbhani.

Groundnut

- At Anand, in early sown groundnut, mean temperature and in late sown crop, minimum temperature during pod development stage showed significant positive relationship with pod yield
- At this centre, high rainfall, rainy days, daily mean temperature and evapotranspiration were found to be favourable weather conditions for obtaining higher pod yield in early sowing compared to delayed sowing.
- Lower yield obtained under late sown conditions compared to early and normal sowing conditions was due to low rainfall, rainy days, low temperature and low sunshine hours during reproductive period of the late sown crop at Anantapur.

Rice

- At Kanpur, higher yield and yield attributing characters were recorded in early sowing (16th July) than in late sowing (5th Aug) due to higher maximum and minimum temperature during vegetative period, higher minimum temperature and rainfall during reproductive period of early sown crop than in late sown crop.
- Variety Satabdi achieved higher radiation use efficiency (RUE) of 0.65 g/MJ and a pre-released cultivar achieved lowest RUE (0.53 g/MJ) at Mohanpur.
- At Raipur, the reason identified for lowest yield of all three varieties under late sowing than in early sowing was lowest per day growing degree days and photothermal units in delayed sowing.
- Higher yield achieved by crop sown on normal date than either early or late sown crop was due to the receipt of optimum rainfall (313 mm) and sunshine hours (97 hrs) during its reproductive period at Ranchi.
- About 27°C of temperature and rainfall of 116 mm during reproductive period were found to be optimum weather conditions for achieving highest grain yield in rice at Samastipur.

Maize

- At Rakh Dhiansar, higher yield obtained in early sowing than in late sowing was possible due to higher per day growing degree days, photothermal units and heliothermal units prevailed during the total crop growing period than in other sowings.
- At this centre, consumptive use of moisture during total growing period of the crop was worked out to be 369 mm and peak evapotranspiration was observed during flowering stage.
- Micrometeorological studies at Udaipur brought out that at 60 and 90 cm heights in 55 to 60 days crop, significantly higher temperature and lower relative humidity prevailed in wider row spacing than in closer row spacing.
- At this centre, rainfall during tasseling to maturity period showed positive influence on both yield and yield attributes.

Sorghum

- Rainfall during milking stage showed significant positive influence on the grain and fodder yield. Rainy days and relative humidity during flower and milking stages also had significant positive effect on grain and fodder yields at Parbhani.

Pearlmillet

- At Solapur, consumptive moisture use of 320 mm during total growing period of the crop was found to be optimum for achieving higher grain yield.
- At this centre, cumulative heliothermal units (HTU) till physiological maturity showed highly significant positive relationship with grain yield and HTU could explain 91 per cent of variation in yield.

Fingermillet

- At Ranichauri, growth indicators like plant height and drymatter were observed to be positively influenced by growing degree days and actual evapotranspiration.

Crop Growth Modelling

Soybean

- Number of days taken and accumulated heat units required for maturity under early sowing (except TAMS-38) decreased with successive delay in sowing. Among the genotypes, TAMS-98-21 accumulated highest number of growing degree days (1866.2°C day) than other varieties at Akola.
- At Jabalpur, the degree days requirement for physiological maturity did not vary much across different sowing dates and varieties.

Groundnut

- The crop sown on normal date (24th July) required highest accumulated GDD (470°C day) and HTU (2287°C hr) to attain 50 per cent flowering compared to early and late sown crop at Anantapur.
- Validation of regression models predicting phenology at Anantapur showed that these models could predict flowering and pod initiation stages accurately (error of ± 1 day) in all three dates of sowing.

Cotton

- At Akola, both number of days taken and growing degree days required from sowing to last picking were higher in early sown crop (182 days and 2269°C day) and reduced with delay in sowing.

Maize

- At Rakh Dhiansar, Campbell and Diaz model perfectly simulated ($R^2 > 0.94$) the drymatter production in all the three dates of sowing.
- Out of three varieties, in HQPM-1 only, the duration and degree days requirement from sowing to maturity were comparatively higher in early sowing (97 days and 1755°C day) than in late sowing (83 days and 1388°C day) at Udaipur.

Rice

- At Faizabad, rice yield simulated with CERES Rice model were in close agreement (error of + 3.7%) with observed yield in case of early sowing (5th July) and prediction error increased with delay in sowing.
- Impact of climate changes on rice yield (cv B-370) studied with the help of CERES Rice model projected a decrease of 19 and 16.9 per cent grain yield with increase of maximum and minimum temperatures, respectively by 2.5°C above normal at Ambala and Karnal districts of Hisar.
- Four weeks delay in sowing shortened the duration of crop varieties PR-116 and PR-118 by 10 and 8 days, respectively and reduced the heat units requirement by 534 and 317°C day, respectively at Ludhiana.
- At Mohanpur, simulation of potential yield under different temperature levels using INFOCROP model showed that with 1°C rise, in maximum and minimum temperatures, potential yield decreased by 830 kg/ha while crop duration decreased marginally by 2 days.
- Duration and degree days requirement has not changed much across different sowing dates and varieties at Ranchi. The varieties under three sowing dates required 1430 to 1457 degree days (°C day) from sowing to maturity.

- At Samastipur, early sown (31st May) crop has taken more number of days (142 days) and accumulated highest number of heat units (2788°C day) to reach maturity and both number of days and heat units decreased with successive delay in sowing.

Pearlmillet

- Drymatter partitioning into different plant parts at periodic intervals of the crop at Solapur showed start of partitioning of drymatter to earhead at soft dough stage and partitioning to earhead at physiological maturity varied between 29 to 38 per cent across different varieties and sowing dates.

Fingermillet

- Number of days from sowing to harvesting increased from 154 to 166 and growing degree days decreased from 1417 to 1296°C day under delayed sowing compared to early sowing at Ranichauri.
- At this centre, among the plant parts, contribution of stem to total drymatter remained high (71-80%) at ear emergence stage and beyond.

Weather Effects on Pests and Diseases

Soybean

- Pest-weather relations brought out that lower maximum and mean temperature and higher humidity conditions are congenial for semilooper population in soybean crop. Maximum temperature in the range of 30 to 31°C and evening relative humidity of 76 to 78 per cent were found to be congenial weather conditions for semilopper pest population at Akola.

Groundnut

- Study on groundnut leaf miner in relation to weather conditions at Anantapur indicated that maximum temperature less than 34.5°C and afternoon relative humidity more than 36 per cent favoured more than 10 per cent GLM damage in groundnut.

Cotton

- At Parbhani, based on step-wise (step up) regression equations between cotton bollworm and different weather parameters, the following regression equations with lower standard error and higher coefficient of determination (R^2) were derived for prediction of bollworm.

Regression equation	R^2	SE
$Y = 2.81 + 0.052RF1 + 0.092RF - 0.494T_{Min} + 0.512BSS1 + 0.135\ RH_{Mean}$	0.73	1.46
$Y = -18.75 + 0.030RF1 + 0.094RF - 0.403T_{Min} - 0.587T_{Min}1 + 0.173BSS1 + 0.179RH_{Mean}1 + 0.221RH_{Mean} - 0.070RHI$	0.77	1.75

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Staff Position at Cooperating Centres during 2010

Centre	Positions Sanctioned and Filled (F) / Vacant (V)					
	Agrometeo-rologist	Junior Agrono-mist	Senior Technical Assistant	Meteoro-logical Observer	Field Assistant	Junior Clerk
Akola	F	-	-	F	F	-
Anantapur	F	F	F	F	F	F
Anand	F	F	V	F	F	F
Bangalore	F	F	F	F	F	F
Bhubaneswar	F	-	-	F	F	-
Bijapur	F	-	-	F	V	-
Dapoli	V	-	-	F	F	-
Faizabad	F	F	F	F	F	F
Hisar	V	F	V	F	F	F
Jabalpur	F	F	F	V	F	V
Jorhat	F	-	-	F	F	-
Kanpur	F	-	-	F	F	-
Kovilpatti	F	F	V	F	F	F
Ludhiana	F	F	F	F	F	F
Mohanpur	F	F	F	V	F	F
Palampur	F	-	-	F	F	-
Parbhani	F	-	-	F	F	-
Ranchi	F	F	V	F	F	F
Ranichauri	F	F	F	V	F	V
Raipur	F	-	-	F	V	-
Rakh Dhiansar	F	-	-	F	F	-
Samastipur	F	-	-	V	F	-
Solapur	F	V	F	V	F	F
Thrissur	F	-	-	F	V	-
Udaipur	F	-	-	F	F	-
Total posts sanctioned	**25**	**12**	**12**	**25**	**25**	**12**
Total posts filled	**23**	**11**	**09**	**20**	**22**	**10**

ALL INDIA COORDINATED RESEARCH PROJECT ON AGROMETEOROLOGY

Center-wise and Head-wise RE allocation (Plan) for the year 2010-11

S. No.	Name of the center	Pay & Allowances	T.A.	Recu-rring	Non Recurring	I.T.	Total ICAR Share
1	Akola	400000	18000	160000	500000	10000	1088000
2	Anand	500000	22000	215000	180000	10000	927000
3	Anantapur	548000	22000	120000	180000	10000	880000
4	Bangalore	700000	22000	180000	180000	10000	1092000
5	Bhubaneswar	407000	18000	160000	180000	10000	775000
6	Bijapur	300000	18000	160000	180000	10000	668000
7	Dapoli	300000	18000	160000	300000	10000	788000
8	Faizabad	548000	22000	215000	180000	10000	975000
9	Hisar	700000	22000	400000	620000	10000	1752000
10	Jabalpur	548000	22000	215000	400000	10000	1195000
11	Jorhat	400000	22000	215000	180000	10000	827000
12	Kanpur	407000	18000	160000	240000	10000	835000
13	Kovilpatti	447000	23000	215000	180000	10000	875000
14	Ludhiana	700000	22000	215000	180000	10000	1127000
15	Mohanpur	700000	22000	215000	650000	10000	1597000
16	Palampur	407000	18000	215000	350000	10000	1000000
17	Parbhani	407000	18000	160000	175000	10000	770000
18	Raipur	407000	18000	160000	350000	10000	945000
19	R.Dhiansar	407000	18000	160000	450000	10000	1045000
20	Ranchi	348000	22000	215000	400000	10000	995000
21	Ranichauri	348000	22000	120000	180000	10000	680000
22	Samastipur	348000	15000	160000	650000	10000	1183000
23	Solapur	343000	22000	205000	175000	10000	755000
24	Thrissur	412000	18000	160000	180000	10000	780000
25	Udaipur	408000	18000	160000	550000	10000	1146000
26	PC Unit	0	0	300000	0	0	300000
	Total	**11440000**	**500000**	**5020000**	**7790000**	**250000**	**25000000**

AICRP on Agrometeorology


XI Biennial Workshop of
AICRP on Agrometeorology
27 - 29 August, 2010
Central Research Institute for Dryland Agriculture
Hyderabad, India