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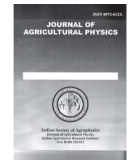

Research Article

Assured Rainfall and Dry Spell Analysis for Crop Planning in East Champaran District of Bihar

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ABSTRACT

Soil moisture is the major limiting factor for crop production under rainfed condition. Therefore, agricultural planning needs to be prepared based on climatic potential of the area. For this, minimum assured weekly rainfall at 10, 25, 50, 75 and 90% probability levels were computed over East Champaran district by using historical weekly rainfall data of Chakia, Mehasi and Motihari rain-gauge stations for a period of 48 years (1965-2012). Initial and conditional probabilities of weekly rainfall and dry spell sequences during summer, *kharif* and *rabi* seasons were worked out for efficient crop planning. Considering 20 mm weekly rainfall, moisture sufficiency period prevailed at 25-35 SMW (Standard meteorological week) at 75% probability level. When weekly water requirement of rice (without water stress) of 50 mm was considered, the stable rainfall period continued for 9 weeks (26-34 SMW) at 50% probability. The probability of dry spell increased significantly after 38 SMW in the district.

Key words: Assured rainfall, Conditional probability, Dry spell, Crop planning

Introduction

Rainfall is the single most important factor which controls crop production under rainfed condition, where almost all agricultural operations are dependent upon the probability of receiving certain amount of rainfall. As compared to other weather elements, the amount and distribution of rainfall in a given location vary greatly. Comprehensive idea on probability of a certain amount of rainfall during a certain period is essential in view of its economic implications of weather sensitive operations for production (Virmani *et al.,* 1982). Water stress for a few days during sensitive growth stages could be disastrous for crop production. A number of risks are involved in rainfed crop production due to uncertainty in rainfall and occurrence of droughts (Misra, 2005). In rainfed areas, rainfall is the only water resource and therefore, the crop planning must be based on potentially high rain water utilization technology. A better understanding of rainfall pattern through rainfall probability analysis should work for sound and efficient cropping systems (Singandhupe *et al.*, 2000). Many workers emphasized the utility of crop plan based on rainfall amount estimated at different probability levels (Sarker *et al*, 1982; Deka and Nath, 2000; Manikandan *et al*., 2014). Hence, studies involving estimation of assured rainfall week-by-week will provide information useful for evaluating climatic potential for agricultural

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development and evolving suitable cropping patterns (Sarker *et al.*, 1982).

East Champaran district is located in north-west alluvial plain zone (Zone I) of Bihar. The area comes under dry sub-humid climate. This paper discusses on computation of assured weekly rainfall and dry spell sequences at different probability levels for enhancing and stabilizing rainfed crop production through rational crop planning in East Champaran district.

Materials and Methods

Weekly rainfall data for the period of 48 years (1965-2012) pertaining to three locations *viz.* Chakia, Mehasi and Motihari were used for district level rainfall analysis. The assured rainfall amount at 10, 25, 50, 75 and 90% probability levels were computed through incomplete gamma distribution technique developed by Thom (1958) and described by Sarker and Biswas (1986 & 1988). The weekly assured rainfall estimated at different probability levels constitutes a series of data that may be expected in different years. Hence, risk involved in getting a certain amount of rainfall during a particular period may be obtained from this analysis.

The equations (Sarker and Biswas, 1986 & 1988) used for computation of minimum assured rainfall are Gamma distribution:

G(X)= q+ pF(X)
F(X)= Gamma distribution function
q= probability of zero precipitation and p=1-q.

$$F(X)=\int_0^x \frac{x^{\gamma-1}e^{(-\frac{x}{\beta})}}{(\beta)^{\gamma}\tau\gamma}dx$$

X, γ, β >0
F(X)=0, when X ≤ 0
Where γ, β are the shape and scale parameters respectively.
τ_{γ} is the gamma function

H(X)= Probability of rain ≤ X

The probability of rain < X, $H(X)=[Q+(1-Q)]=\int_0^x \frac{x^{\gamma-1}e^{(-\frac{x}{\beta})}}{(\beta)^{\gamma}\tau\gamma}dx$, Q is the empirical probability of zero rain, being the ratio of occasions of zero rain to the total number of occasions and X includes zero rain also.

The probability of rain ≥ X,

$$P_x=1-H(X)=(1-Q)=\left\{\int_0^x \frac{x^{\gamma-1}e^{(-\frac{x}{\beta})}}{(\beta)^{\gamma}\tau\gamma}dx\right\}$$

Rainfall at probability levels can be estimated by iteration process, and termed as assured rainfall with respective probability. Using software based on these methodologies, the amount of assured rainfall at different probability level was computed.

Probabilities of 2 and 3 consecutive dry weeks with threshed rainfall amount of 10 mm per week were worked out for the district following Olderman and Frere (1982). Initial and conditional probabilities of getting weekly threshold rainfall (10, 20, 30 and 50 mm per week) were computed as suggested by Robertson (1976) and adopted by Virmani *et al.* (1982) and Samui *et al.* (2013). With this analysis, initial and conditional probabilities were obtained.

Initial probability

P (D) = Probability of dry week,

P (W) = Probability of wet week,

Conditional probability

P (W/W) = Probability of a wet week followed by a wet week

P (D/D) = Probability of a dry week followed by a dry week

P (D/W) = Probability of a dry week followed by a wet week

P (W/D) = Probability of a wet week followed by a dry week

Results and Discussion

Assured weekly rainfall probability

At 50% probability level, weekly threshold rainfall of 20 mm was available during 23 to 40 standard meteorological weeks (SMW) (Table 1).

Table 1. Assured weekly rainfall (mm) at probability levels in East Champaran district (data base: 1965-2012)

SMW	Date	Assured weekly rainfall (mm) at probability of					Mean weekly rainfall (mm)
		90%	75%	50%	25%	10%	
1	1 – 7 Jan	0.3	0.8	2.1	4.5	7.8	2.3
2	8 – 14 Jan	0.3	0.8	1.9	3.8	6.3	1.7
3	15 – 21 Jan	0.3	0.9	2.7	6.1	11	3.5
4	22– 28 Jan	0.3	1.0	2.8	6.3	11.2	3.6
5	29 Jan – 4 Feb	0.3	1.0	2.9	6.4	11.4	3.6
6	5 – 11 Feb	0	0.0	2.7	8.1	12	2.7
7	12 – 18 Feb	0	0.1	3.7	9.3	13.4	3.7
8	19 – 25 Feb	0	0	3.5	10.1	15.1	3.5
9	26 Feb – 4 Mar	0.3	0.8	1.8	3.5	5.7	1.5
10	5 – 11 Mar	0.5	0.9	1.5	2.4	3.4	0.8
11	12 – 18 Mar	0.3	0.8	2	3.9	6.4	1.8
12	19 – 25 Mar	0.3	0.9	2.3	4.7	7.9	2.4
13	26 Mar – 1 Apr	0.3	0.9	2.4	5	8.6	2.6
14	2 – 8 Apr	0.5	0.9	1.8	3.2	4.9	1.3
15	9 – 15 Apr	0.2	0.8	2.4	5.6	10.2	3.1
16	16 – 22 Apr	0.2	0.9	4	11.4	23.2	7.6
17	23 – 29 Apr	0.4	1.4	4.2	9.6	17.2	6.0
18	30 Apr – 6 May	0.5	1.9	6.3	15.4	28.5	10.2
19	7 – 13 May	0.6	2.3	6.8	15.7	28.4	10.4
20	14 – 20 May	0.6	2.6	8.6	21.1	39.5	14.5
21	21 – 27 May	0.9	3.6	11.9	29.1	54.1	20.3
22	28 May – 3 Jun	0.9	3.7	11.9	28.6	52.8	19.9
23	4 – 10 Jun	2	7.2	21.4	49	87.9	34.5
24	11 – 17 Jun	3.1	9.5	25	52.9	90.9	37.2
25	18 – 24 Jun	7.6	19.9	42.1	80.2	129.3	56.9
26	25 Jun – 1 Jul	10.9	25.8	56	104.3	166.1	74.5
27	2 – 8 Jul	11.8	28.7	63.4	119.8	192.2	85.6
28	9 – 15 Jul	13.9	30.4	62	111	172.2	79.7
29	16 – 22 Jul	20	40.3	76.9	131.6	198.3	95.4
30	23 – 29 Jul	12.9	29.4	61.6	112.4	176.5	80.5
31	30 Jul – 5 Aug	9.6	23.1	50.4	94.5	151	67.4
32	6 – 12 Aug	9.9	22.1	45.7	82.7	129.1	59.0
33	13 – 19 Aug	10.1	27.3	65.5	130.4	216.1	93.1
34	20 – 26 Aug	12.6	29	61.3	112.3	177	80.4
35	27 – 2 Sep	11.6	23	43.5	73.8	110.6	53.1
36	3 – 9 Sep	4	12.8	34.5	74.3	128.8	52.7
37	10 – 16 Sep	8.5	20	43.2	80.3	127.7	57.2
38	17 – 23 Sep	2	8	25.5	60.9	112.1	43.4
39	24 – 30 Sep	1.7	8	28.4	72.1	137.1	52.1
40	1 – 7 Oct	0.9	5.3	21.6	59.5	118.3	43.5
41	8 – 14 Oct	0.6	2.5	7.9	18.5	33.8	12.5
42	15 – 21 Oct	0.2	1.4	6.1	17.5	35.6	12.2
43	22 – 28 Oct	0.2	0.8	2	4.2	7.2	2.0
44	29 Oct – 4 Nov	0.4	0.8	1.4	2.4	3.7	0.8
45	5 – 11 Nov	0.2	0.7	2.3	5.8	10.9	3.3
46	12 – 18 Nov	0.4	0.8	1.3	2.1	3	0.6
47	19 – 25 Nov	0.4	0.7	1.2	1.8	2.6	0.4
48	26 Nov – 2 Dec	0.4	0.7	1.2	2	2.9	0.5
49	3 – 9 Dec	0.4	0.7	1.2	2	2.8	0.5
50	10 – 16 Dec	0.2	0.7	1.6	3.3	5.5	1.4
51	17 – 23 Dec	0.3	0.7	1.3	2.2	3.4	0.6
52	24 – 31 Dec	0.2	0.8	2.6	6.2	11.4	3.5
Annual		929.2	1090.1	1287.2	1508.2	1727.3	1311.2

SMW: Standard meteorological week

The rainfall amount of 20 mm per week was found to provide enough moisture for sowing of upland crops and therefore, 20 mm rainfall per week in the beginning of the season was considered optimum (Ramana Rao *et al*., 1983). Since this amount of rainfall was fairly adequate at all growth stages of rainfed upland crops (Subramaniam and Rao, 1989), number of weeks with assured rainfall ≥ 20 mm could be the length of cropping period. Accordingly, period for rainfed cropping in East Champaran district was estimated at 18 weeks. At this probability (50%) level, sowing of rainfed crops could be planned during 23 SMW. However at higher probability (75%) level, with lesser operating risks, rainfed crop growing period ranges from 25 to 35 SMW with sowing week starting at 25 SMW. Total annual rainfall at 50 and 75% probability levels were 1287.2 and 1090.1 mm, respectively. The earliest sowing of rainfed crops with 20 mm weekly rainfall at 10% probability (one in 10 yrs) could be set at 16 SMW. Period with 20 mm weekly rainfall at 75% probability is the core rainfall period, during which drought hazard remains low and thus, this could be regarded as moisture sufficiency period (Sarkar, 1994). Emphasis should be given on those crops/crop varieties whose growing cycle is completed within the period matching with water availability period as identified.

Initial and conditional probabilities of rainfall

Initial and conditional probabilities of receiving 10, 20, 30 and 50 mm rainfall per week during summer, *kharif* and *rabi* seasons for the district are presented in Table 2. Various degrees of wetness with different thresholds of rainfall represent approximately 0.15 to ≤ 1.0 of potential evapotranspiration for different seasons and crop phenophases (Virmani *et al.*, 1982). The soil of the district is predominantly medium textured. At least 20 mm rainfall is required for land preparation and sowing work. An initial probability of receiving 20 mm rainfall per week (PW) exceeded 50% during the period from 23 to 39 SMW, while during 25-35 SMW, the probability was ≥ 75%. The results at higher probability level implied that if a farmer intends to operate at lower risk level (*e.g.* 75% probability), he has to choose crops and cropping pattern in such a way that the durations of crops is 3-4 weeks less than those operating at higher risk level (*e*.g. 50% probability). In such situations, the sowing schedules need to be adjusted in such a way that critical phases of crop growth could occur during the weeks with maximum probability of having 20 mm rainfall (Subramaniam and Rao, 1989).

The P(W/W) with 20 mm rainfall at ≥50% probability in the district started at 23 SMW and ended at 39 SMW. Considering the evapotranspiration and percolation losses from rice fields of 3 and 4 mm d^{-1} , respectively in eastern India, water requirement of rice without stress could be taken as 50 mm in a week (Singh and Singh, 2000). Chaudhary and Tomar (1999) and Dey *et al.* (2011) considered this amount as a stable rainfall for rice. Based on this, the growing period of rainfed rice in the district was estimated at 9 weeks (26-34 SMW at 50% probability). Considering 20-25 days for seeding and 25-30 days for maturity stage of short to medium duration rice (*Prabhat, Dhanlaxmi, Richhariya, Turanta, Santosh etc*) with 90-120 days to maturity could be recommended for the district. While considering P(W/D), periods of 28-29, 31 and 33-35 SMW showed probability >7% (Fig. 1).

Dry spell probability

Probability of occurrence of dry spell of consecutive two and three weeks remains very low (<10%) during major part of *kharif* crop growing season (Fig. 2). However, chances of getting dry spell of consecutive two and three weeks are high during summer and *rabi* seasons. The probabilities of dry spell of consecutive two and three weeks increases significantly after 38 SMW. Thus, chances of crops experiencing moisture stress are very high after 38 SMW. Dry spell coinciding with sensitive phases can adversely affect the growth and yield of crop. To the contrary, the wet spell during certain phases of growth is beneficial.

Table 2. Initial and conditional probabilities of weekly rainfall in East Champaran district (data base: 1965-2012)

SMW	10 mm			20 mm			30 mm			50 mm			Mean RF*
	W	W/W	W/D	W	W/W	W/D	W	W/W	W/D	W	W/W	W/D	(mm)
Summer/*Zaid* season													
11	0.06	0	0.06	0.02	0	0.02	0	0	0	0	0	0	1.8
12	0.10	0	0.11	0.02	0	0.02	0.02	0	0.02	0	0	0	2.4
13	0.10	0.40	0.07	0.02	0	0.02	0	0	0	0	0	0	2.6
14	0.02	0	0.02	0	0	0	0	0	0	0	0	0	1.3
15	0.06	0	0.06	0.02	0	0.02	0.02	0	0.02	0.02	0	0.02	3.1
16	0.21	0.67	0.18	0.15	0	0.15	0.06	0	0.06	0.06	0	0.06	7.6
17	0.23	0.30	0.21	0.08	0	0.10	0.06	0	0.07	0	0	0	6.0
18	0.27	0.45	0.22	0.19	0.50	0.16	0.13	0	0.13	0.02	0	0.02	10.2
19	0.35	0.54	0.29	0.21	0.22	0.21	0.10	0	0.12	0.02	0	0.02	10.4
20	0.46	0.41	0.48	0.27	0.30	0.26	0.19	0	0.21	0.06	0	0.06	14.5
21	0.54	0.68	0.42	0.40	0.54	0.34	0.23	0.44	0.18	0.10	0.33	0.09	20.3
22	0.52	0.54	0.50	0.38	0.32	0.41	0.25	0.27	0.24	0.04	0.20	0.02	19.9
23	0.67	0.80	0.52	0.52	0.78	0.37	0.44	0.58	0.39	0.27	1.00	0.24	34.5
***Kharif* season**													
24	0.71	0.69	0.75	0.56	0.64	0.48	0.48	0.62	0.37	0.31	0.38	0.29	37.2
25	0.88	0.85	0.93	0.77	0.74	0.81	0.67	0.74	0.60	0.46	0.53	0.42	56.9
26	0.85	0.83	1.00	0.81	0.81	0.82	0.71	0.72	0.69	0.58	0.55	0.62	74.5
27	0.92	0.93	0.86	0.90	0.90	0.89	0.77	0.79	0.71	0.54	0.54	0.55	85.6
28	0.88	0.86	1.00	0.83	0.81	1.00	0.81	0.76	1.00	0.60	0.58	0.64	79.7
29	0.96	1.00	0.67	0.88	0.90	0.75	0.83	0.87	0.67	0.75	0.79	0.68	95.4
30	0.98	0.98	1.00	0.81	0.88	0.33	0.67	0.75	0.25	0.56	0.64	0.33	80.5
31	0.90	0.89	1.00	0.83	0.85	0.78	0.73	0.78	0.63	0.52	0.59	0.43	67.4
32	0.88	0.88	0.80	0.75	0.80	0.50	0.71	0.74	0.62	0.52	0.56	0.48	59.0
33	0.88	0.88	0.83	0.85	0.89	0.75	0.75	0.76	0.71	0.63	0.76	0.48	93.1
34	0.92	0.90	1.00	0.81	0.80	0.86	0.73	0.67	0.92	0.58	0.53	0.67	80.4
35	0.92	0.91	1.00	0.81	0.77	1.00	0.65	0.57	0.85	0.40	0.36	0.45	53.1
36	0.83	0.89	0.25	0.67	0.74	0.33	0.54	0.61	0.41	0.27	0.32	0.24	52.7
37	0.88	0.90	0.75	0.67	0.66	0.69	0.63	0.58	0.68	0.48	0.46	0.49	57.2
38	0.71	0.74	0.50	0.56	0.66	0.38	0.46	0.57	0.28	0.31	0.39	0.24	43.4
39	0.71	0.68	0.79	0.52	0.63	0.38	0.46	0.55	0.38	0.31	0.47	0.24	52.1
40	0.60	0.65	0.50	0.38	0.40	0.35	0.29	0.36	0.23	0.21	0.27	0.18	43.5
41	0.35	0.28	0.47	0.17	0.11	0.20	0.13	0	0.18	0.02	0	0.03	12.5
***Rabi* season**													
42	0.23	0.29	0.19	0.15	0.13	0.15	0.13	0.17	0.12	0.13	0	0.13	12.2
43	0.08	0.09	0.08	0.02	0	0.02	0.02	0	0.02	0	0	0	2.0
44	0.04	0	0.05	0	0	0	0	0	0	0	0	0	0.8
45	0.10	0	0.11	0.06	0	0.06	0.04	0	0.04	0.02	0	0.02	3.3
46	0.02	0.20	0	0	0	0	0	0	0	0	0	0	0.6
47	0.02	0	0.02	0	0	0	0	0	0	0	0	0	0.4
48	0.02	0	0.02	0	0	0	0	0	0	0	0	0	0.5
49	0.02	0	0.02	0	0	0	0	0	0	0	0	0	0.5
50	0.02	0	0.02	0.02	0	0.02	0.02	0	0.02	0	0	0	1.4
51	0.02	0	0.02	0.02	0	0.02	0	0	0	0	0	0	0.6
52	0.13	0	0.13	0.04	0	0.04	0.04	0	0.04	0.02	0	0.02	3.5
1	0.09	0.17	0.07	0.02	0.50	0	0.02	0.50	0	0	0	0	2.3
2	0.04	0	0.05	0.02	0	0.02	0.02	0	0.02	0	0	0	1.7
3	0.15	0	0.15	0.06	0	0.06	0.02	0	0.02	0	0	0	3.5
4	0.15	0.14	0.15	0.04	0	0.04	0.02	0	0.02	0	0	0	3.6
5	0.15	0.14	0.15	0.06	0	0.07	0	0	0	0	0	0	3.6
6	0.08	0.29	0.05	0.06	0.33	0.04	0	0	0	0	0	0	2.7
7	0.13	0	0.14	0.06	0	0.07	0	0	0	0	0	0	3.7
8	0.15	0	0.17	0.06	0	0.07	0.02	0	0.02	0	0	0	3.5
9	0.06	0.14	0.05	0.02	0	0.02	0	0	0	0	0	0	1.5
10	0	0	0	0	0	0	0	0	0	0	0	0	0.8

RF*- Rainfall

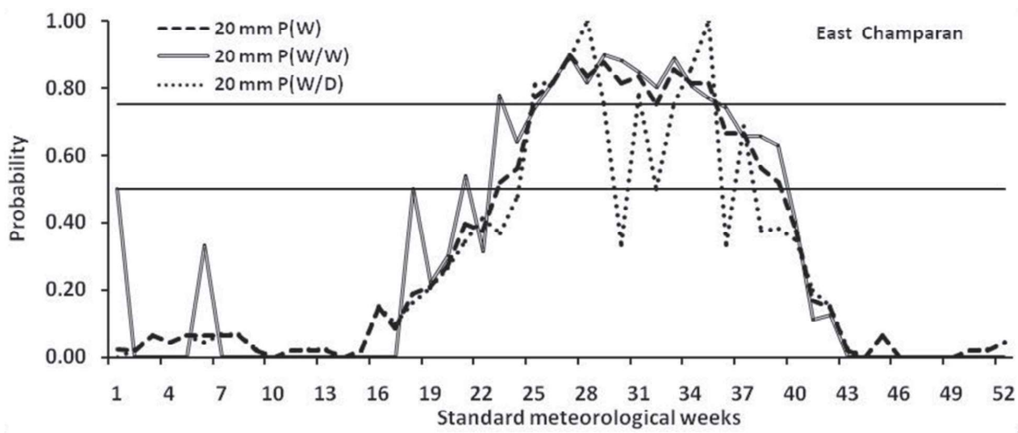

Fig.1. Initial and conditional probabilities of receiving weekly rainfall ≥ 20 mm in East Champaran district, Bihar (data base: 1965-2012)

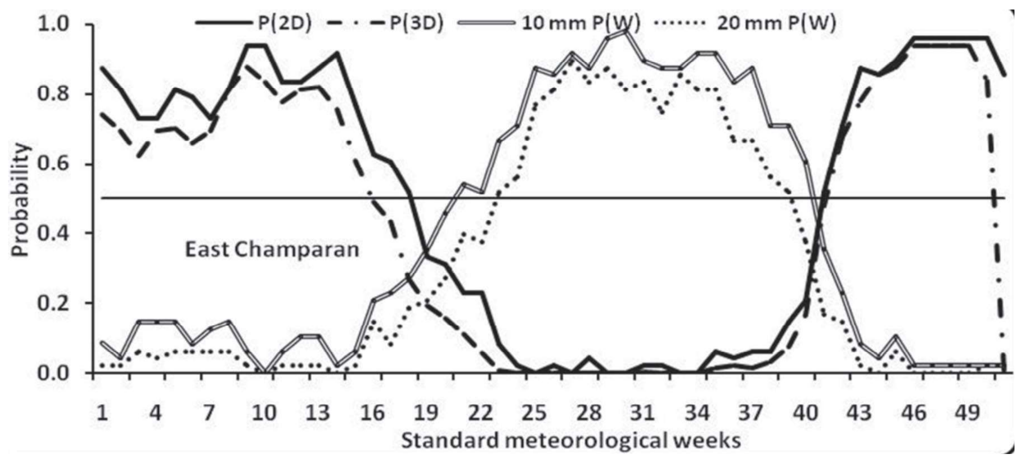

Fig. 2. Probabilities of receiving dry spell for consecutive two weeks, P(2D) and three weeks, P(3D) along with initial probability, P(W) for 10 and 20 mm threshold rainfall over East Champaran district, Bihar (data base: 1965-2012)

Conclusions

Selection of crops or variety must match with the water availability in the area, and scheduling of irrigation must follow the critical growing stages to avoid water stress. Hence, the cropping plan should be tailored on a rational basis with available rainfall resource of the district to enhance agricultural production. The findings of the study could help in identifying wetness or dryness conditions during growing season and thereby helping farmers to schedule irrigation needs or conserve excessive rainfall which can be used as supplemental irrigation for higher productions.

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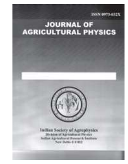

Research Article

Effect of Weather Variability on Yield and Thermal Utilization for Attaining Different Phenological Stages in Mustard

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ABSTRACT

An experiment was conducted on the sandy loam soil of research farm of IARI, New Delhi during *Rabi* 2010-11 and 2011-12 with mustard cultivar (Pusa Gold, Pusa Jaikisan and Pusa Bold) sown on three different dates with the aim for generating different weather conditions during various phenological stages. Different crop growth parameters and accumulated thermal indices were calculated during different phenological stages. Results showed that the early sown crop had longer crop span than the late sown. Delay in sowing reduced the value of thermal indices as well as biomass and seed yield in both the year resulted that the weather during crop growing period influence the crop production. The heat use efficiency as well as the photo thermal index decreased from germination to the maturity. The biomass and yield had positive correlation with different accumulated thermal index. Therefore, thermal index could be used for studying biomass accumulation at different phenological stages and for assessing crop yield forecast.

Key words: Mustard, Biomass, Thermal indices, Heat use efficiency

Introduction

Oil seed crop plays an important role in India's economy. Among different oil seed crops, mustard (*Brassica* spp.) is the second most important and contributing nearly 30% of total oil seed production in the country. Micro-environment influences the growth and yield of the crop. Depending upon the crop condition, the micro environment varies during the crop growing period. Various environmental factors affecting the crop growth are light intensity, photo synthetically active radiation, temperature, relative humidity, wind speed, soil temperature and soil moisture. Radiation and temperature has key role in influencing crop production. Gouri *et al*. (2005) reported that growing degree days can be used for estimating the occurrence of different phenological events during crop growing period in relation to temperature. Accumulated GDD can estimate the harvest date as well as crop development stage (Roy *et al*., 2005).

The duration of a particular stage of growth was directly related to the temperature and this duration could be predicted using the sum of daily air temperature (Wang, 1960). Dwyer and Stewart (1986) reported that the thermal time is an independent variable to describe the plant development. Effect of temperature on phenology and yield of wheat crop can be studied under field conditions through accumulated heat unit system (Haider *et al.*, 2003 and Pandey *et al.*, 2010). Rao *et al.* (1999) reported that heat use efficiency is the efficiency of utilization of heat in terms of

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dry matter accumulation, depends on crop type, genetic factors and sowing time and has great practical application.

In the present study of accumulated thermal indices were calculated under variable weather conditions. Weather variability causes substantial fluctuations in crop productivity of crops. In order to optimize growth and seed yield in the crop, optimum weather condition is required during different phenological stages of the crop. Therefore, crop weather relationship could helps in determining proper time for sowing and crop yield forecast.

Materials and Methods

Field experiments with three varieties of mustard (Pusa Gold, Pusa Jaikisan and Pusa Bold) sown on different dates (Oct., 22nd & 30th and Nov., 15th during *rabi* 2010-11, Oct., 14th & 31st and Nov., 16th during *rabi* 2011-12) were conducted at research farm of IARI, New Delhi (latitude: 28°38′23″ N, longitude: 77°09′27″ E) for estimating the influence of accumulated heat unit on yield of mustard under variable weather conditions. The seeds (5 kg/ha) were sown in random block design followed by the standard agronomic practices. Numbers of days taken to reach different phenological stage during the crop growth period were noted day to day observations. Crop growth parameters such as biomass, leaf area index at different phenological stages as well as seed yield were measured.

The climate of Delhi is semi-arid with hot summer and mild winter season. The normal and actual weekly maximum temperature during the crop growing period in both the year is sown in Fig 1. The mean maximum temperature during the entire growing period of the crop was 24 and 25°C during r*abi* 2010-11 and 2011-12, respectively as compared to the normal value (25°C). The corresponding value of mean minimum temperature during the crop growing period was 10 and 9°C, respectively as compared to the normal value 10°C (Fig. 2). The mean maximum and minimum temperature was 1°C lower than normal during 2010-11 and 2011-12

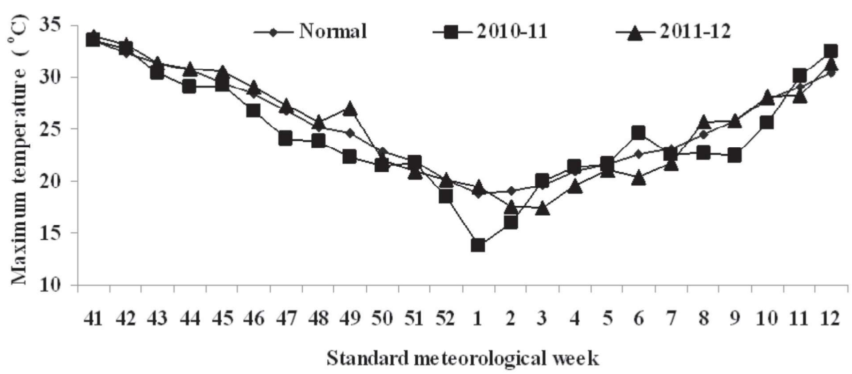

Fig. 1. Normal and actual maximum temperature during *rabi* 2010-11 and 2011-12

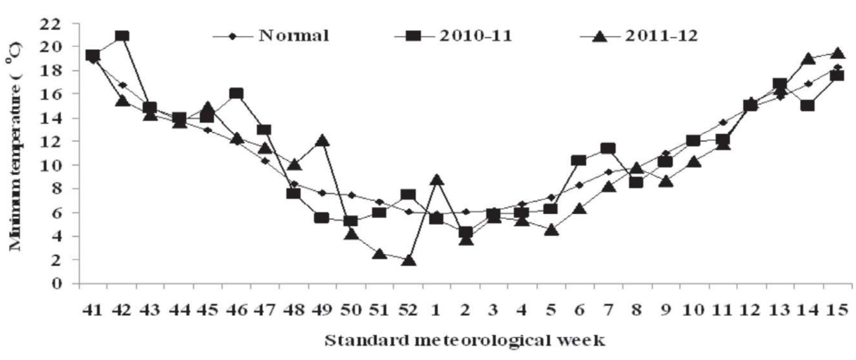

Fig. 2. Normal and actual minimum temperature during *rabi* 2010-11 and 2011-12

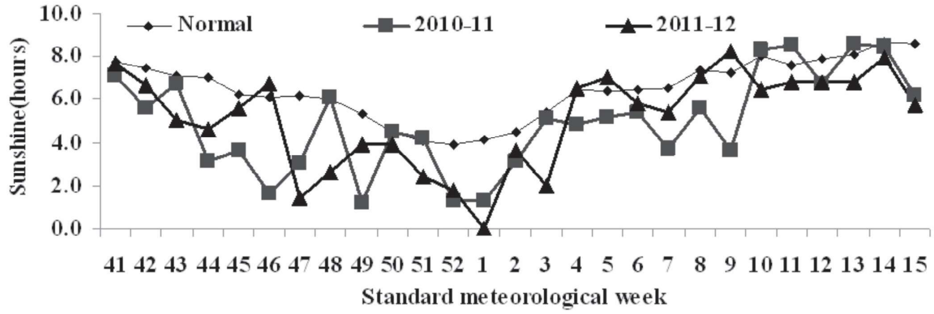

Fig. 3. Normal and actual maximum sunshine hours during *rabi* 2010-11 and 2011-12

respectively. The mean value of bright sunshine hours during crop growing period of *rabi* 2010-11 and 2011-12 was found to be 4.9 and 5.1 hours, respectively as compared to the normal value 6.5 hours (Fig. 3).

The plant samples were collected at different phenological stages for measuring the leaf area index and biomass. Different accumulated thermal indices were calculated at different phenological stages using the following formula:

Growing degree days, GDD = $\Sigma\{ ((T_{max} + T_{min})/2) – T_{base}\}$

Where T_{max} = daily maximum temperature (^oC), T_{min} = daily minimum temperature (^oC) and T_{base} = base temperature (5^oC)

Heilo thermal units (HTU) = $\Sigma \{(((T_{max} + T_{min})/2) – T_{base})$X bright sunshine hours}

Photo thermal unit (PTU) = $\Sigma \{(((T_{max} + T_{min})/2) – T_{base})X N\}$

where N is the maximum possible sunshine hours

Relative temperature disparity (RTD) = $\Sigma ((T_{max} - T_{min})/ T_{max}) X 100$

Photo thermal index (PTI) = GDD/growing days

Heat use efficiency (HUE) = Yield/GDD

GDD, HTU, PTU and RTD were accumulated from the date of sowing to each phenological stage. The analysis was done using MS Excel and SPSS10.0.

Results and Discussion

The number of days required for germination to harvest was found to be more in cultivars Pusa Jaikisan and Pusa Bold as compared to the corresponding value in the Pusa Gold during both the years. During year 2011-12, the total growing period was found to be more for all the three varieties as compared to the year 2010-11 for first and third sown crop except for Pusa Gold during the 2010-11, the crop duration was more for third sown crop as compared to the corresponding value during 2010-11. For second sown crop the crop duration was found to be more during 2010-11 as compared to the corresponding value during 2011-12 for the all three varieties (Table 1).

Thermal indices

The accumulated value of growing degree days for different phenological stage under variable weather conditions for both the years are sown in Table 1. Result showed that earlier sown crop had higher value of growing degree days as compared to late sown crop during 2011-12. But during *rabi* 2010-11, the second sown crop had higher value of growing degree days followed by first and third sown crop. The cultivar Pusa Gold required less value of accumulated growing degree days as compared to cultivars Pusa Jaikisan and Pusa Bold in both the years. The cultivar Pusa Gold required 1772, 1568, 1294°C accumulated growing degree days during 2011-12 and 1635, 1588, 1357°C during 2010-11 for first, second and third sown crop, respectively. The cultivar Pusa Jaikisan and Pusa Bold required 2013, 1735, 1728°C accumulated growing degree days during 2011-12 and 1784, 1896, 1632°C during 2011-12 for first, second and third sown crop respectively. Pandey *et al.* (2010) also reported lower consumption of heat unit under

Table 1. Number of days and accumulated growing degree days (°C day) for different phenological stages of mustard sown under

Phenological stages	First sowing			Second sowing			Third sowing		
	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold
***Rabi* (2010-11)**									
100% Germination	9 (176.1)	10 (192.6)	10 (192.6)	5 (99.3)	6 (115.4)	6 (115.4)	6 (107.7)	7 (121.1)	7 (121.1)
Flower initiation	60 (812.0)	62 (829.3)	64 (848.2)	56 (705.7)	58 (717.1)	60 (730.2)	62 (574.7)	63 (581.8)	65 (596.1)
50% Flowering	66 (859.6)	68 (872.7)	69 (882.8)	60 (730.2)	62 (750.1)	64 (763.5)	66 (603.0)	67 (609.9)	70 (638.5)
50% Pod formation	93 (1035.9)	95 (1051.6)	97 (1071.2)	94 (967.3)	96 (986.2)	99 (1025.0)	90 (846.5)	92 (875.9)	95 (903.9)
Physiological maturity	138 (1533.6)	144 (1617.5)	144 (1617.5)	132 (1417.3)	149 (1719.6)	149 (1719.6)	121 (1228.7)	133 (1455.8)	133 (1455.8)
Harvest maturity	145 (1634.9)	153 (1784.4)	153 (1784.4)	142 (1588.4)	158 (1895.9)	158 (1895.9)	128 (1356.9)	142 (1632.2)	142 (1632.2)
***Rabi* (2011-12)**									
100% Germination	11 (233.7)	15 (300.6)	15 (300.6)	4 (86.6)	4 (86.6)	4 (86.6)	8 (135.8)	8 (135.8)	8 (135.8)
Flower initiation	50 (844.7)	57 (944.3)	59 (963.3)	51 (709.9)	53 (724.4)	54 (728.6)	46 (508.1)	51 (552.3)	52 (561.6)
50% Flowering	55 (915.3)	62 (987.1)	63 (993.9)	56 (737.8)	57 (743.3)	59 (757.7)	51 (552.3)	56 (586.2)	58 (595.0)
50% Pod formation	93 (1201.7)	100 (1244.2)	102 (1257.7)	75 (874.8)	78 (906.1)	80 (913.5)	94 (881.6)	97 (915.3)	100 (958.7)
Physiological maturity	141 (1645.7)	154 (1830.7)	154 (1830.7)	131 (1432.4)	141 (1591.5)	141 (1591.5)	118 (1196.7)	137 (1542.9)	137 (1542.9)
Harvest maturity	150 (1772.1)	164 (2012.5)	164 (2012.5)	140 (1568.0)	149 (1735.4)	149 (1735.4)	124 (1294.0)	145 (1728.2)	145 (1728.2)

*Value in the bracket are showing the value of accumulated growing degree days (°C day) delayed sowing. The requirement of GDD was lower for late growing than the normal growing conditions. This was due to un-favourable weather conditions for late sown crop, the duration of crop growing period decreased as compared to normal sown crop. Similar findings were observed in wheat by Masoni *et. al.* (1990), Bishnoi *et al.* (1995) and Tripathi *et. al.* (2004)

The requirement of helio thermal unit for different phenolological stage under different weather conditions are shown in Table 2. It was observed from the results that Pusa Gold had lesser requirement for the heilo thermal unit as compared to cultivars Pusa Jaikisan and Pusa bold in both the years. The total value of heilo thermal unit from germination to harvest for cultivars Pusa Gold was 7158, 6886 and 6283°C days hour during *rabi* 2010-11 and 8772, 7574 and 6106°C days hour during *rabi* 2011-12, for first, second and third sown crop, respectively. For Pusa Bold and Pusa Jaikisan the total value of heilo thermal unit from germination to harvest was 8148, 9554, 8695°C days hour during *rabi*. 2010-11 and 10384, 8594, 9327°C days hour during *rabi* 2011-12 for first, second and third sown crop. Masoni *et. al.* (1990) reported that HTU for different phenological stage in wheat was decreased with delay in the sowing.

The variation in photo-thermal units (PTU) under different weather condition for both the year for different phenological stages are shown in Table 2. Results showed that Pusa Gold had lower value of photo thermal units as compared to the cultivar Pusa Jaikisan and Pusa Bold. It was observed that sowing dates influence the accumulation of photo thermal units. The total value of photo thermal unit from germination to harvest for cultivars Pusa Gold was 17590, 17159 and 14713°C days hour during *rabi* 2010-11 and 19075, 16883 and 13946°C days hour during *rabi* 2011-12, for first, second and third sown crop, respectively. For Pusa Bold and Pusa Jaikisan the total value of heilo thermal unit from germination to harvest was19374, 20912, 18079°C days hour during *rabi*. 2010-11 and 21946, 18904 and 19261°C days hour during *rabi* 2011-12 for first, second and third sown crop respectively.

The photo thermal index for consecutive phenological stage was also calculated and shown in Table 3. It was observed that the photo thermal index gradually decreased from germination to maturity in all dates of sowing in both the years this indicating that daily heat consumption was decreased towards the maturity being highest during germination and lowest during pod formation.

The relative temperature disparity for different phenological stages under variable weather condition is shown in the Table 3. Cultivar Pusa Gold had lower value of relative temperature disparity as compared to the corresponding value of Pusa Jaikisan and Pusa Bold in both the year under variable weather condition. The total value of RTD was found to be decreased with delay in sowing period in both the year except during 2010-11 Pusa Jaikisan and Pusa Bold had higher value for second sown followed by first and third sown crop.

Heat use efficiency was calculated for different phenological stages for mustard crop under different weather condition for both the year (Table 4). It was observed that heat use efficiency gradually decreased from germination to maturity in both the year under different weather conditions, indicates that the heat consumption decreased towards the maturity. HUE decreased with delay in sowing after 31st October. Kingra and Kaur (2012) reported that the thermal unit required to attain a particular phenological stages decreased as sowing was delayed in groundnut. Kingra and Kaur (2012) also reported that the photo thermal index gradually decreased from emergence to maturity in all the three dates of sowing during all the years being highest at emergence and lowest during maturity of the crop.

Correlation between heat indices with biomass and yield

As the ambient daily temperatures are highly variable therefore the response of the plants to the thermal environment for their growth and development can better be expressed through the accumulated thermal indices instead of

Table 2. Accumulated helio thermal unit and photo thermal unit (°C day hour) for different phenological stages of mustard sown under variable weather condition

Phenological stages	First sowing			Second sowing			Third sowing		
	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold
***Rabi* (2010-11)**									
100% Germination	963.8	986.9	986.9	357.8	357.8	357.8	261.6	368.8	368.8
	(1938.5)	(2117.7)	(2117.7)	(1077.7)	(1250.5)	(1250.5)	(1130.6)	(1270.3)	(1270.3)
Flower initiation	3013.1	3085.2	3161.5	2343.7	2343.7	2381.9	1805.1	1851.2	1910.6
	(8597.6)	(8773.6)	(8966.4)	(7394.2)	(7510.3)	(7643.7)	(5923.2)	(5996.9)	(6146.3)
50% Flowering	3161.5	3199.7	3199.7	2381.9	2381.9	2412.7	1959.6	1992.0	2131.0
	(9082.5)	(9215.9)	(9318.4)	(7643.7)	(7846.2)	(7983.0)	(6218.3)	(6290.4)	(6589.7)
50% Pod formation	3760.2	3848.7	3960.5	3269.1	3409.2	3615.1	3191.3	3284.2	3378.5
	(10901.3)	(11066.8)	(11273.1)	(10111.0)	(10313.2)	(10731.0)	(8824.8)	(9148.2)	(9457.0)
Physiological maturity	6271.0	7022.0	7022.0	5669.5	8065.7	8065.7	5481.1	7206.6	7206.6
	(16401.9)	(17383.5)	(1783.5)	(15134.8)	(18742.7)	(18742.7)	(13185.0)	(15910.3)	(15910.3)
Harvest maturity	7158.1	8147.8	8147.8	6885.6	9553.8	9553.8	6283.4	8694.7	8694.7
	(17589.5)	(19374.2)	(19374.2)	(17159.2)	(20911.6)	(20911.6)	(14713.1)	(18079.2)	(18079.2)
***Rabi* (2011-12)**									
100% Germination	1510.7	1834.7	1834.7	421.6	421.6	421.6	477.3	477.3	477.3
	(2615.0)	(3349.4)	(3349.4)	(938.8)	(938.8)	(938.8)	(1421.1)	(1421.1)	(1421.1)
Flower initiation	4188.0	4585.2	4653.7	2924.3	2965.7	2979.3	1572.0	1572.7	1572.7
	(9104.1)	(10124.1	(10318.0)	(7435.6)	(7583.1)	(7626.4)	(5234.4)	(5687.1)	(5782.0)
50% Flowering	4512.0	4755.5	4785.4	3016.7	3037.4	3040.7	1572.7	1611.5	1656.9
	(9827.3)	(10560.0)	(10629.2)	(7720.0)	(7775.5)	(7922.7)	(5687.1)	(6034.9)	(6126.2)
50% Pod formation	5144.0	5275.1	5345.9	3160.4	3278.6	3291.8	3232.8	3485.6	3814.5
	(12754.2)	(13197.0)	(13338.6)	(9122.9)	(9447.0)	(9524.0)	(9192.5)	(9567.5)	(10053.9)
Physiological maturity	7969.0	9187.9	9187.9	6661.9	7762.3	7762.3	5485.0	7834.4	7834.4
	(17609.7)	(19766.0)	(19766.0)	(15280.4)	(17163.9)	(17163.9)	(12793.2)	(16962.1)	(16962.1)
Harvest maturity	8772.2	10384.2	10384.2	7574.3	8593.8	8593.8	6105.6	9326.8	9326.8
	(19075.1)	(21946.2)	(21946.2)	(16883.0)	(18903.8)	(18903.8)	(13946.3)	(19261.6)	(19261.6)

*value in the bracket are showing the value of photo thermal unit (°C day hour)

Table 3. Photo thermal index (^{o}C day day^{-1}) and relative temperature disparity for different phenological stages of mustard sown under variable weather condition

Phenological stages	First sowing			Second sowing			Third sowing		
	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold
				***Rabi* (2010-11)**					
100% Germination	19.6 (492.6)	19.3 (544.3)	19.3 (544.3)	19.9 (310.8)	19.2 (362.6)	19.2 (362.6)	17.9 (305.3)	17.3 (361.6)	17.3 (361.6)
Flower initiation	13.5 (3520.9)	13.4 (3669.4)	13.3 (3813.3)	12.6 (3420.1)	12.4 (3565.3)	12.2 (3671.1)	9.3 (3999.8)	9.2 (4057.5)	9.2 (4217.8)
50% Flowering	13.0 (3958.6)	12.8 (4064.3)	12.8 (4104.2)	12.2 (3671.1)	12.1 (3753.5)	11.9 (3855.5)	9.1 (4295.7)	9.1 (4376.7)	9.1 (4590.9)
50% Pod formation	11.1 (5713.0)	11.1 (5876.6)	11.0 (5999.6)	10.3 5975.2)	10.3 (6111.1)	10.4 (6303.4)	9.4 (5895.2)	9.5 (5974.2)	9.5 (6133.5)
Physiological maturity	11.1 (8395.8)	11.2 (8770.0)	11.2 (8770.0)	10.7 (8122.5)	11.5 (9088.0)	11.5 (9088.0)	10.2 (7632.8)	10.9 (8282.2)	10.9 (8282.2)
Harvest maturity	11.3 (8831.8)	11.7 (9263.2)	11.7 (9263.2)	11.2 (8697.7)	12.0 (9537.7)	12.0 (9537.7)	10.6 (8016.6)	11.5 (8732.0)	11.5 (8732.0)
				***Rabi* (2011-12)**					
100% Germination	21.2 (614.4)	20.0 (838.1)	20.0 (838.1)	21.7 (289.0)	21.7 (289.0)	21.7 (289.0)	17.0 (502.1)	17.0 (502.1)	17.0 (502.1)
Flower initiation	16.9 (2814.7)	16.6 (3191.5)	16.3 (3335.6)	13.9 (3215.4)	13.7 (3387.5)	13.5 (3487.5)	11.0 (3306.7)	10.8 (3595.5)	10.8 (3627.8)
50% Flowering	16.6 (3104.3)	15.9 (3581.2)	15.8 (3669.9)	13.2 (3686.5)	13.0 (3782.0)	12.8 (3954.8)	10.8 (3595.5)	10.5 (3909.2)	10.3 (4095.7)
50% Pod formation	12.9 (6008.2)	12.4 (6503.5)	12.3 (6660.3)	11.7 (5055.7)	11.6 (5227.3)	11.4 (5383.7)	9.4 (6659.2)	9.4 (6844.6)	9.6 (7030.2)
Physiological maturity	11.7 (9324.5)	11.9 (10123.9)	11.9 (10123.9)	10.9 (8865.4)	11.3 (9454.5)	11.3 (9454.5)	10.1 (8199.2)	11.3 (9201.4)	11.3 (9201.4)
Harvest maturity	11.8 (9910.3)	12.3 (10658.4)	12.3 (10658.4)	11.2 (9408.5)	11.6 (9876.2)	11.6 (9876.2)	10.4 (8534.3)	11.9 (9577.2)	11.9 (9577.2)

*value in the bracket are showing the value of relative temperature disparity

Table 4. Heat use efficiency (g m^2 C^{-1} day^{-1}) for different phenological stages of mustard sown under variable weather condition

Phenological stages	First sowing			Second sowing			Third sowing			CV
	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	Pusa Gold	Pusa Jaikisan	Pusa Bold	%
***Rabi* (2010-11)**										
100% Germination	6.5	10.9	10.1	11.6	23.0	20.4	5.6	8.8	8.9	50.96
Flower initiation	1.4	2.5	2.3	1.6	3.7	3.2	1.0	1.8	1.8	40.66
50% Flowering	1.3	2.4	2.2	1.6	3.5	3.1	1.0	1.7	1.7	40.20
50% Pod formation	1.1	2.0	1.8	1.2	2.7	2.3	0.7	1.2	1.2	41.53
Physiological maturity	0.7	1.3	1.2	0.8	1.5	1.4	0.5	0.7	0.7	37.85
Harvest maturity	0.7	1.2	1.1	0.7	1.4	1.2	0.4	0.7	0.7	36.85
***Rabi* (2011-12)**										
100% Germination	5.2	8.0	8.2	12.5	27.4	26.6	3.2	10.1	12.5	68.83
Flower initiation	1.5	2.5	2.6	1.5	3.3	3.2	0.9	2.5	3.0	36.18
50% Flowering	1.3	2.4	2.5	1.5	3.2	3.0	0.8	2.3	2.9	37.60
50% Pod formation	1.0	1.9	2.0	1.2	2.6	2.5	0.5	1.5	1.8	41.35
Physiological maturity	0.7	1.3	1.4	0.8	1.5	1.4	0.4	0.9	1.1	35.80
Harvest maturity	0.7	1.2	1.2	0.7	1.4	1.3	0.3	0.8	1.0	37.41

temperatures. Growing Degree Days (GDD) are the most common and simple ways of quantifying the thermal environment. Degree-day based approach is based on the premise that plants need a certain definite amount of accumulated heat to fulfill their requirement for phenological development. Differentiation in phenological events does not take place until this requirement is met. The basic concept of heat unit assumes a linear or logarithmic relationship between growth and temperature, which is predicted by Vant Hoff's Law. Heat unit is a measure of departure of mean daily temperature from a base temperature below which the internal biochemical activity ceases. The response of plant growth parameters (LAI, biomass and seed yield) to the prevailing thermal environment (represented by thermal units GDD) can be depicted by curves, termed as thermal response curves. Thermal response curves may serve as ready reference for expressing the relationship of growing degree-days with biomass production and yield and these curves can be used for predicting biological or economical yield of a crop well in advance, besides in crop simulation studies. The correlation between plant growth parameters and different heat indices are shown in Table 5. Positive correlations were observed between growth parameters biomass and yield with accumulated thermal indices (GDD, HTU, PTU, RTD). From the results, it was observed that heat unit can be used for prediction of the yield. The correlation coefficient was found to be higher value for yield than biomass.

It was observed that third order polynomial equations in yield that is 60 to 98 per cent variation in production could be explained through the accumulated thermal indices, when crop was sown in variable weather conditions (Fig. 4). Biomass production in *Brassica* species were reported to be positively correlated with

Table 5. Correlation coefficient between thermal indices, biomass and yield

Thermal indices	GDD	HTU	PTU	RTD
***Rabi* (2010-11)**				
Yield	0.95	0.74	0.94	0.96
Biomass	0.81	0.65	0.81	0.82
***Rabi* (2011-12)**				
Yield	0.84	0.78	0.83	0.86
Biomass	0.54	0.60	0.58	0.50

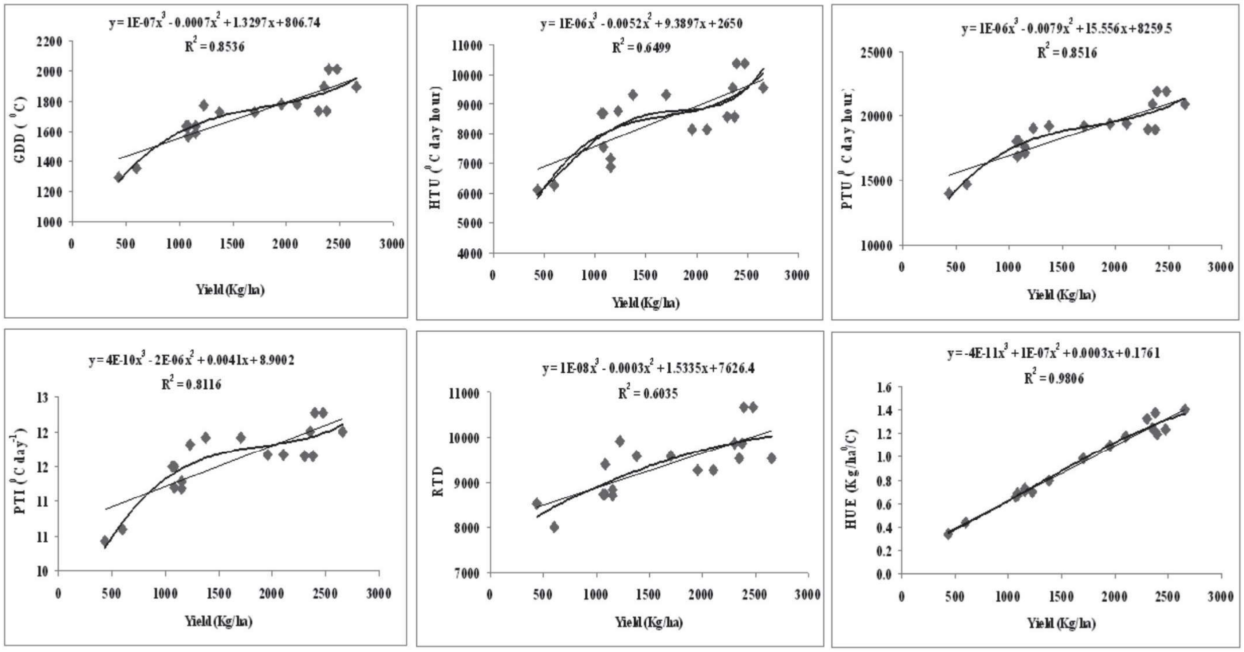

Fig. 4. Relationship between thermal indices and seed yield

GDD accumulation during the crop growth period (Chakravarty and Sastry, 1983 and Patel and Mehta, 1987).

Leaf area index (LAI)

Leaf area index is an important parameter for the crop growth studies since it is useful in interpreting the capacity of a crop for producing dry matter in terms of the intercepted utilization of radiation and amount of photosynthesis synthesized. During the crop season (*rabi* 2011-12), the maximum leaf area index under different weather condition was found to be 2.6,3.59 and 3.04 for first sown crop, 3.63, 4.10 and 5.76 for second sown crop, 2.04, 2.56 and 2.14 for Third sown crop in Pusa Gold, Pusa Jaikisan and Pusa Bold respectively at 50% flowering. During *rabi* 2010-11 crop season, the maximum leaf area index under different weather condition was found to be 3.35, 4.49 and 3.81 for first sown crop, 4.87, 5.41 and 5.49 for second sown crop, 2.06, 2.54 and 2.51 for third sown crop in Pusa Gold, Pusa Jaikisan and Pusa Bold, respectively at 50% flowering (Fig. 5). Sowing of crop after 31st October reduced the leaf area index in both the year in all the three varieties. Cultivar Pusa Gold had lower value of leaf area index as compared to Pusa Jaikisan and Pusa Bold in both the year under variable weather conditions.

Among the plant growth parameters, leaf area index is the most important parameters exhibiting overall performance of the growth and development under varying weather conditions.

Rao and Agarwal (1986) reported that, the maximum LAI was found at 90 DAS and thereafter declined towards maturity. Working on *Brassica napus* cv. B.O. 54, *B. juncea* cv. Pusa bold and *B. campestris,* Kar and Chakravarty (1999) reported that LAI was lower in a season with higher temperatures (2 to 3°C) during vegetative and grain filling stages as compared to the season with relatively lower temperatures in the same period. Working on three varieties Pusa Jaikisan, Varuna and Agrani under Delhi condition, Roy *et al.* (2005) reported that delay of a fortnight sowing from 1st October to 1st November reduced LAI significantly in all three cultivars.

Biomass production

Biomass production of the plant is the process of organic substance formation of carbohydrates, the products of photosynthesis and from small

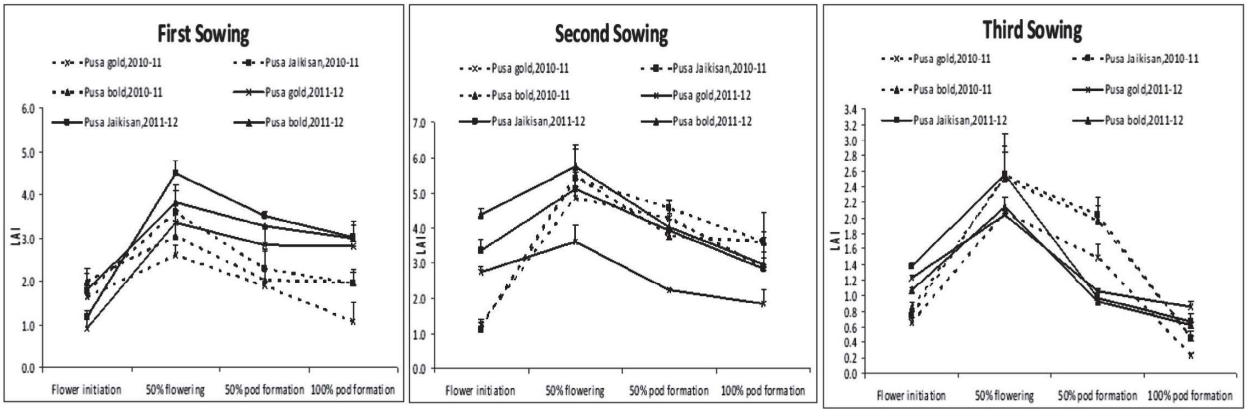

Fig. 5. Leaf area index in different varieties of mustard sown under different weather conditions

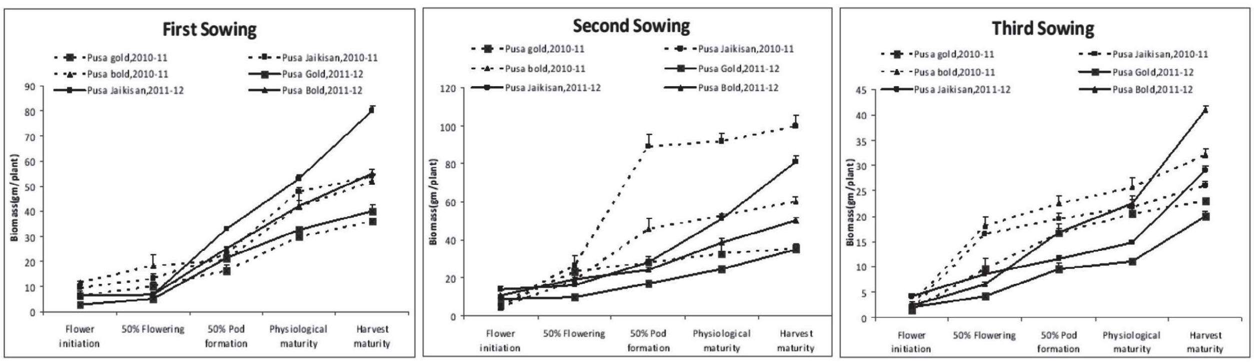

Fig. 6. Biomass (g/plant) in different varieties of mustard sown under different weather conditions

quantity of inorganic substance absorbed by roots from the soil. The timely accumulation of dry matter by the crop is important as it is followed by adequate translocation of assimilates to the sink resulting in higher yield. The higher biomass in the first sown crop may be due to favourable weather during crop growth period.

The maximum above ground biomass in the first, second and third sown crop was 40, 80, 55 g/plant, 35, 81, 50 g/plant and 20, 29, 41 g/ plant for Pusa Gold, Pusa Jaikisan and Pusa Bold, respectively during r*abi* 2010-11. During r*ab*i 2011-12, the maximum above ground biomass in the first, second and third sown crop was 36, 54, 52 g/plant, 36, 100 60 g/plant and 23, 26, 32 g/ plant for Pusa Gold, Pusa Jaikisan and Pusa Bold, respectively. Pusa Jaikisan and Pusa Bold had higher value of biomass production as compared to Pusa Gold in both the year under variable weather conditions (Fig. 6). Pusa Jaikisan had highest value of biomass followed by Pusa Bold and Pusa Gold in first and second sown crop however Pusa Bold had higher value of biomass followed by Pusa Jaikisan in third sown crop. The biomass production levels obtained in the present study and the reduction of biomass production due to late sowing are in conformity with the earlier findings in mustard and soybean (Kar and Chakravarty, 2001; Vashisth *et al.*, 2011; 2012).

Radiation use efficiency (RUE)

During the crop growing period the peak value of RUE (g/MJ) during 2010-11 was 1.35, 1.75, 1.42 g/MJ for Pusa Gold, Pusa Jaikisan, Pusa Bold in first sown crop at 134 days after sowing while the peak value of RUE for second sown crop was 1.57 g/MJ for Pusa gold at 126 days after sowing and 4.44 g/MJ for Pusa Jaikisan at 86 days after sowing and 2.27g/MJ for Pusa Bold at 97 days after sowing. During 2011-12, the peak value of RUE was 1.53, 2.46, 1.99 g/MJ