MAUSAM, **56**, 2 (April 2005), 417-424

551.586 : 551.521 : 633

Heat unit requirement, radiation, water use and photoperiod during the growing season of toria (*Brassica campestris* variety toria)

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(*Received 03 December 2002, Modified 13 February 2004*)

सार – इस शोध पत्र में जोरहाट और श्यामखुंटा क्षेत्र की तोरिया की फसल के लिए अपेक्षित उष्मा की मात्रा, जल उपयोग, प्रकाशीय ताप और सौर ताप की मात्रा तथा प्रकाश संश्लेषित क्रियाशील विकिरण (पी. ए. आर.) की मात्रा के संदर्भ में वहां की घटना वैज्ञानिक गतिविधियों का पता लगाने के लिए जोरहाट और श्यामखुंटा क्षेत्र की तोरिया की फसल (एम–27 किस्म) के वर्ष 1986–87 से लेकर वर्ष 1992–93 तक की अवधि के कृषि मौसम वैज्ञानिक आँकडों का उपयोग किया गया है। परिणाम यह बताते है कि श्यामखुंटा क्षेत्र में प्रकाशीय ताप और सौर ताप की मात्रा, जल उपयोग तथा पी. ए. आर. की गतिविधियाँ जोरहाट की अपेक्षा अधिक थी। देश काल के अनुसार उष्मा उपयोग क्षमता (एच. यू. इ.) और विकिरण उपयोग क्षमता (आर. यू. इ.) में भिन्नता का पता चला है। इन स्थानों की अगेती फसलों में इनके उपयोग की मात्रा अपेक्षाकृत अधिक पाई गई है। फसल बोने से लेकर पौधों में फूल आने और फली लगने से लेकर फसल पकने की अगल–अलग अवस्थाओं की समय अवधि (दिनों की) और उष्मा के उपयोग की मात्रा के मध्य वक्ररेखी संबंध का पता लगाया गया है। यह संबंध दोनों स्थानों पर निरंतर सकारात्मक पाया गया है।

ABSTRACT. The agrometeorological data of toria (variety M-27) at Jorhat and Shayamakhunta for the period 1986-87 to 1992-93 were used for assessing phenological development in relation to heat unit, water use, photothermal and heliothermal unit and photosynthetically active radiation (PAR) requirement at Shayamakhunta and Jorhat. Photothermal, heliothermal unit, water use and PAR were higher at Shayamakhunta than that of Jorhat. Heat use efficiency (HUE) and radiation use efficiency (RUE) also showed variations in time and space which were comparatively higher in early sown crops. A curvilinear relationship between duration (days) and heat units was derived seperately for sowing to flowering and pod formation to physiological maturity stages which showed consistent positive correlations at both locations.

Key words − Photothermal unit, Heliothermal unit, Photosynthetically active radiation, Heat use efficiency, Radiation use efficiency.

1. Introduction

Next to groundnut, rape seed and mustard are the most important oilseed crops in India and occupy an area of 6.3 million hectare with a total production of 4.87 million tones (FAO, 1993). They belong to genus Brassica of the family cruciferae and are divided mainly into 4 species, *viz*., *Brassica campestris* (L.) (variety yellow and brown sarsoon), *B. juncea* (L.) (brown or Indian mustard or Rai/Laha), *B. campestris* (L.) (variety toria) and *Eruca sativa* (M). (Taramira or Tara). They are grown in rabi season from September-October to February-March and require relatively dry and cold weather during its growing period for satisfactory growth. Brassica is a short day plant and flowering response increases with short days of eight hours photoperiod (Friend, 1968). Shading reduces number of flowers, pods and seeds per pod and pod size and its yield is largely influenced by environmental factors mainly temperature and radiation. The increase of temperature by 3° C – 4° C during pod formation and seed filling stages affects crop growth and its yield (Bose, 1973). The yield is positively correlated to the number of primary and secondary branches, number of days to flowering, plant height, length of main branches and number of seeds per pod (Singh *et al*., 1969). The high temperature also accelerates growth and development, hasten seed maturity and decrease oil content (Shiv Raj, 1978). Thus temperature and photoperiod are the two most important weather elements that affect the growth and development of the crop. This has been studied extensively in several crops but prediction of field phenology based on environmental factors has been less satisfactory (Reddy, 1993). The objectives of the present study were to estimate the water use, heat unit (GDD), the

TABLE 1

Growth, duration and yield of toria (M-27)

Station and variety	Date of sowing	Date of harvesting	Duration (days)	Yield (kg/ha)
Jorhat M-27	14 Nov ′86	13 Feb ′87	91	1459
	28 Oct ′88	31 Jan ′89	95	1540
	23 Nov ′89	05 Mar ′90	102	N.A.
	21 Nov ′90	04 Mar ′91	103	N.A.
	28 Nov ′91	05 Mar ′92	99	2426
	10 Nov ′92	20 Feb ′93	102	2072
Shayamakhunta M-27	13 Dec ′86	04 Mar ′87	81	313
	14 Dec ′88	06 Mar ′89	83	237
	24 Nov ′89	23 Feb ′90	91	239
	07 Dec ′90	02 Mar ′91	85	236
	27 Nov ′91	29 Feb ′92	94	347
	18 Nov ′92	16 Feb ′93	90	261

N. A. – Not available

effect of heat unit (GDD) and radiation distribution on the phenological behaviour and maturity of the crop toria (M-27) under two different environmental conditions.

2. Materials and methods

The present study was based on 6 years data of both Jorhat (26° 47′ North, 94° 12′ East, and 87 metre above sea level) and Shayamakhunta (21° 56′ North, 86° 46′ East, and 50 metre above sea level). Under these two locations, the crop variety was same (M-27) which comes under *Brassica campestris* (L.) variety toria. The physiological characteristics of the variety are short duration (85-95 days), dwarf (85 cm tall), spreading type, high profuse branching, bold and black seeds, high oil content (44.6 %) and average yield (12-18 quintal per hectare) (Das, 1997). The soil at Jorhat is sandy clay loam and the same at Shayamakhunta is silty clay loam. Regarding climatic features, Jorhat belongs to humid climate and the Shayamakhunta comes under moist subhumid climate (Chowdhury *et al*., 1995). Rabi season rainfall in two stations are very less and crop growth depends mainly on stored soil moisture. The minimum temperature of Jorhat during the rabi season is about 13° C with a maximum of 27° C. The same for Shayamakhunta is 19° C and 30° C respectively (Chowdhury *et al*., 1995). The daily weather data namely, maximum and minimum temperature, bright hours of sunshine, relative humidity and the crop yield and phenological informations of M-27 variety for Jorhat and Shayamakhunta observatories for 6 years (1986-87 to 1992-93) were collected from India Meteorological Department, Pune. This is for computing heat units or growing degree days (GDD) and heat use efficiency (HUE), photosynthetically active radiation (PAR) and photo thermal unit (PTU) and heliothermal unit (HTU), water use (ET) and water use efficiency (WUE) (Table 2) during the growing seasons of the crop. The evapotranspiration (ET) data of the toria (M-27) crop for six years (1986-87 to 1992-93) each from gravimertic lysimeter at Jorhat and Shayamakhunta were also collected. The heat units were computed using 5° C as base temperature to correlate phenological development and maturity of the M-27 variety of toria crop (Kar and Chakravarty, 1999) which was used in the study for characterising thermal response in the crop. Heat use efficiency (HUE) of the crop production per unit degree day with respect to economic (seed) yield has been computed using the following formulae to compare the relative performance of the crop with respect to utilization of heat (Kar and Chakravarty, 1999; Rao *et al*., 1999)

$$\text{HUE} = \frac{\text{Ecnomic (seed) yield in Kg/ha}}{\text{Accumulated heat units in degree day}}$$

$$\left(\text{kg ha}^{-1}\text{ degree day}^{-1}\right) \quad (1)$$

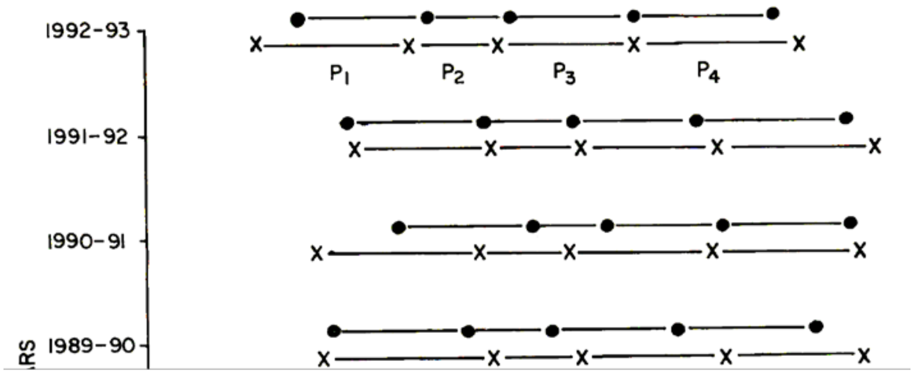

Fig. 1. Phenological calendar of Toria (M-27)

The incoming solar radiation (Rs) was estimated in the following way

$$Rs = R_A (a + b.n/N) \quad (2)$$

Where,

R_A = Theoretical amount of radiation that would reach the earth's surface in the absence of the atmosphere (measured from Smith sonian tables)

n = Actual duration of sunshine hours

N = Maximum possible duration of sunshine hours

a and b = coefficients

The values of a and b are 0.25 and 0.50 respectively for the latitudes of the study area concerned (Mani and Rangarajan, 1982). A factor of 0.45 was used (Meek *et al.*, 1984) to convert incoming solar radiation values (Rs) into photosynthetically active radiation (PAR).

Radiation use efficiency (RUE) of the crop in terms of dry matter production (here economic or seed yield) per unit of PAR absorbed by the crop was also estimated (Kar and Chakravarty, 1999., Khichar *et al.*, 2000) using the following formulae

$$\text{RUE}(\text{gm/MJ}) = \frac{\text{Economic seed yield in gm/m}^2}{\text{Cumulative observed PAR in MJ/m}^2}$$

The photo thermal units (PTU) and heliothermal units (HTU) (Agrawal *et al.*, 1999; Hundal and Kingra, 2000) were also estimated in the study. The phenological stages of the crop as already described by earlier workers (Chaudhary *et al*., 1999) were followed here.

3. Results and discussion

3.1. *Phenological development of the crop*

The duration of various phenophases with respect to season, sowing dates and locations showed wide variations. The crop had maturity period ranging from 91

TABLE 2

Agrometeorological variables during various phenophases of the crop

Year	GDD (°C day)					PAR (MJm $^{-2}$)					ET (mm)				
	P1	P2	P3	P4	Total	P1	P2	P3	P4	Total	P1	P2	P3	P4	Total
Jorhat															
1986-87	397	203	273	376	1249	68	39	66	90	263	46.5	34.8	71.9	59.1	212.3
1988-89	435	234	298	388	1355	77	39	64	71	251	49.2	33.1	71.4	48.5	202.2
1989-90	338	182	344	345	1209	83	45	66	76	270	44.1	26.4	54.5	46.1	171.1
1990-91	415	206	284	387	1292	81	46	73	84	284	34.4	35.7	70.5	59.7	200.3
1991-92	304	160	285	374	1123	59	44	59	84	246	36.0	32.5	72.4	60.1	201.0
1992-93	418	163	284	398	1263	73	43	57	81	254	34.9	31.4	60.2	46.4	172.9
Mean	385	191	295	378	1249	74	43	64	81	261	40.9	32.3	66.8	53.3	193.3
S.D.	47.3	259	23.2	16.8	71.6	8.2	2.8	5.2	6.1	12.8	5.9	3.0	6.9	6.4	15.6
C.V.(%)	12.3	13.6	7.9	4.4	5.7	11.1	6.9	8.1	7.6	4.9	14.6	9.2	10.4	11.9	8.1
Shayamakhunta															
1986-87	269	212	314	403	1198	67	50	75	84	276	51.1	72.3	101.8	92.5	317.7
1988-89	304	184	356	449	1293	79	50	77	96	302	175.4	112.7	96.9	94.5	479.5
1989-90	350	200	354	450	1354	84	48	84	90	306	66.6	76.2	107.0	97.5	347.3
1990-91	320	185	349	488	1342	73	38	77	95	283	41.9	34.9	92.3	91.7	260.8
1991-92	348	203	360	483	1394	75	47	76	99	297	43.6	38.9	74.4	72.1	229.0
1992-93	371	192	364	420	1347	77	48	72	96	293	34.8	39.1	111.7	101.8	287.4
Mean	327	196	350	449	1321	76	47	77	93	292	68.9	62.4	97.4	91.7	320.3
S.D.	33.8	10.1	16.6	30.7	62.5	5.2	4.1	3.6	4.9	10.5	48.6	27.9	12.1	9.4	80.7
C.V.(%)	10.3	5.1	4.7	6.8	4.7	6.9	8.8	4.7	5.3	3.6	70.6	44.7	12.4	10.2	25.2

Year	Heliothermal unit (HTU)					Photothermal unit (PTU)					HUE kg ha $^{-1}$ deg.day $^{-1}$	RUE gmMJ $^{-1}$	WUE kg ha $^{-1}$ mm $^{-1}$
	P1	P2	P3	P4	Total	P1	P2	P3	P4	Total			
Jorhat													
1986-87	3156	1360	2066	3365	9947	4212	2131	2899	4126	13368	1.17	0.59	6.87
1988-89	3589	1287	2078	2231	9185	4751	2505	3129	3182	13567	1.14	0.61	7.62
1989-90	2501	1329	1832	1863	7525	3573	1923	3722	3940	13158	N.A.	N.A.	N.A.
1990-91	3144	1373	1988	2670	9175	4395	2173	3041	4351	13960	N.A.	N.A	N.A.
1991-92	2128	1104	1501	2010	6743	3184	1691	3084	4273	12232	2.16	0.98	12.07
1992-93	2518	1255	1278	2733	7784	4456	1709	1741	4431	12337	1.64	0.81	11.98
Mean	2839	1285	1791	2479	8394	4095	2022	2936	4050	13104			
S.D.	496.5	90.3	301	511.3	1118.1	542.6	284.4	594.1	419.7	628.3			
C.V.(%)	17.5	7.1	16.8	20.6	13.3	13.3	14.1	20.2	10.4	4.8			
Shayamakhunta													
1986-87	2048	2067	3077	3928	11120	3056	2484	3489	5054	14083	0.26	0.11	0.96
1988-89	2410	1803	3512	5011	12736	2827	2034	4001	5944	14806	0.18	0.08	0.49
1989-90	2976	1783	3924	3520	12203	3277	2480	4314	4738	14809	0.18	0.08	0.69
1990-91	2256	1073	3400	5538	12267	2971	2023	4063	6652	15709	0.17	0.08	0.90
1991-92	2407	1717	3346	4057	11527	3496	2522	4520	5521	16059	0.25	0.12	1.52
1992-93	2608	1813	3229	3787	11455	3629	2229	4349	4540	14747	0.19	0.09	0.91
Mean	2451	1709	3415	4307	11885	3209	2295	4124	5408	15037			
S.D.	289.9	304.9	265.3	719.6	558.2	285.6	211.3	335.1	727.5	660.3			
C.V.(%)	11.8	17.8	7.8	16.7	4.7	8.9	9.2	8.1	13.5	4.4			

P1 – Vegetative, P2 - Flowering, P3 - Pod formation, P4 - Physiological maturity

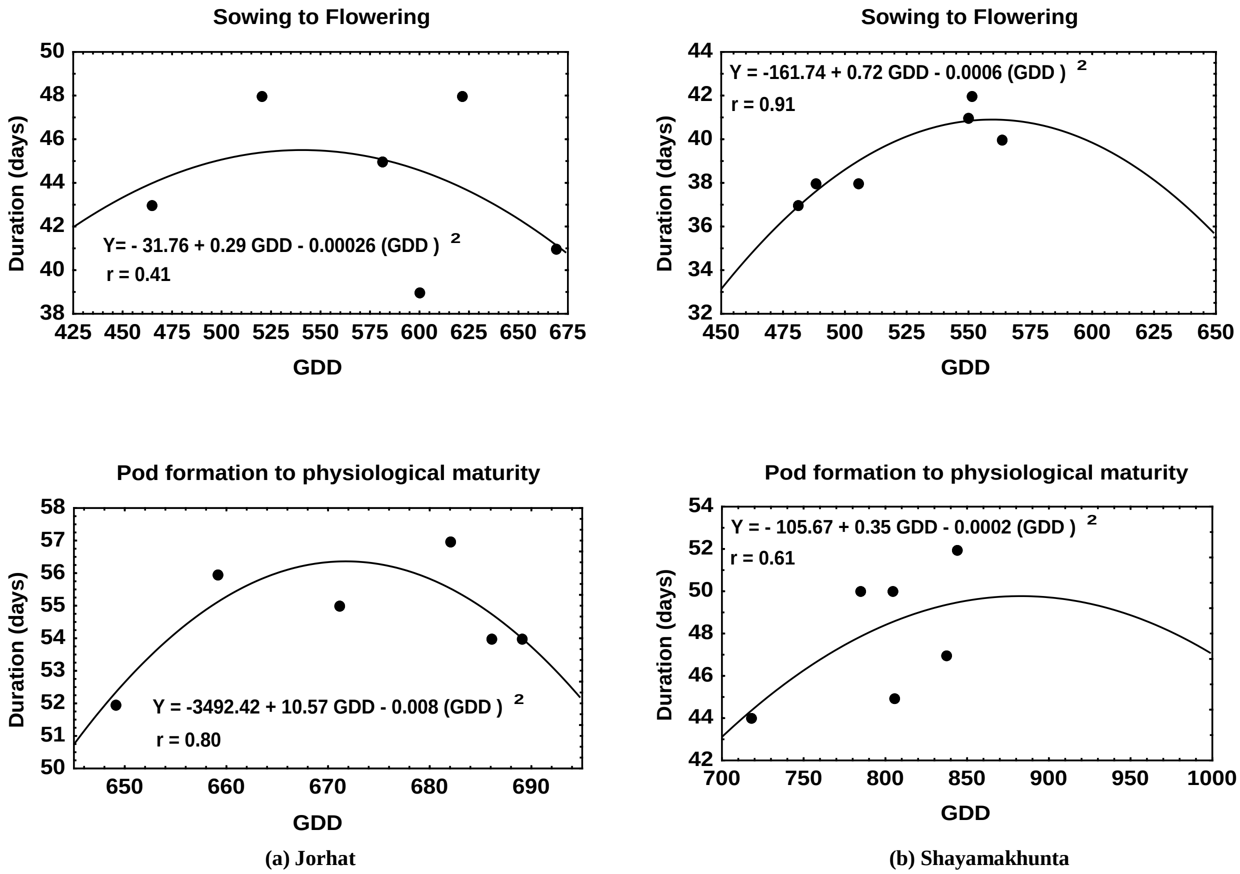

Fig. 2. Influence of GDD on growth stages of Toria (M-27)

days to 103 days at Jorhat (mean 99 days) and 81 days to 94 days at Shayamakhunta (average-87 days) (Table 1).

The duration for different phenophases at both locations showed variations in the number of days taken by the crop for completion of each phenophase (Fig. 1). In general, the vegetative and the physiological maturity stages varied more as compared to the flowering and the pod formation stages which was more evident at Shayamakhunta. This is mainly attributed to the prevailing temperature and sunshine hours during the growing season.

3.2. *Growing degree days (GDD) based phenology and the heat use efficiency (HUE) of the crop*

GDD or heat unit is widely used for describing the temperature responses on growth and development of the crops. It was evident that same genotype of toria (M-27) sown at different locations and different dates has used different GDD/heat unit during different phenophases of the crop (Table 2). For different sowing dates, GDD for emergence to maturity ranged from 1123° C day (1991-92) to 1355° C day (1988-89) at Jorhat and 1198° C day (1986-87) to 1394° C day (1991-92) at Shayamakhunta. The average value of GDD for the same variety of M-27 at Jorhat was 1249° C day with a variability of 6 % and the same for Shayamakhunta was 1321° C day and 5 % respectively. The phenophasewise GDD was also worked out at both locations, showed the lowest value at flowering stage and highest value at vegetative and physiological maturity stage. Accumulated GDD of mustard ranging from 1452°C day to 1992°C day at Hisar (Haryana) was obtained taking a base temperature of 5° C (Rao *et al.*, 1999). The same for *Brassica sps*., values were obtained in the order of 1612° C day to 2550° C day at different dates of sowing in New Delhi (Kar and Chakravarty, 1999).

Heat use efficiency of toria (variety M-27) at both locations was estimated to determine the number of GDD required to produce unit amount of economic grain/pod yield. At Jorhat, HUE was varied from 1.14 kg ha^{-1} degree day^{-1} (1988-89) to 2.16 kg ha^{-1} degree day^{-1} (1991-92) and at Shayamakhunta, the same was comparatively low in all the years. The higher HUE at Jorhat may be attributed to higher economic yield as observed in Table 1. Experiment elsewhere recorded the highest HUE of 2.1 kg ha^{-1} degree day^{-1} and the lowest of 0.72 kg ha^{-1} degree day^{-1} (Rao *et al*., 1999). The actual /bright sunshine hours and photo period/day lengths of both locations were used in association with GDD to estimate the heliothermal units (HTU) and photothermal units (PTU) respectively of the toria (M-27) during the growing season of the crop (Table 2). The mean accumulated HTU was 8393° C day at Jorhat and 11885° C day at Shayamakhunta where as for PTU it was 13104° C day and 15037° C day respectively at both locations. The mean PTU and HTU also worked out at various phenophases, showed the two peaks at vegetative stage and physiological maturity stage at Jorhat and at Shayamakhunta, the same was at pod formation and physiological maturity stage.

The classical heat unit or GDD concept cannot be used accurately to predict the physiological events under wide climatic regimes (Quinby *et al*., 1973) as the effect of temperature on duration of different phases is curvilinear. Brown (1960) developed curvilinear relationships between phenological rate of development and temperature for soyabean. Cox and Martin (1974) also reported the same curvilinear relationship for groundnut. In this study, a curvilinear relationship between durations (days) and GDD was developed separately for toria from sowing to flowering (vegetative and flowering) and from pod formation to physiological maturity stages at both the locations which showed positive correlations during whole growing season (Fig. 2).

3.3. *Photosynthetically active radiation (PAR) and radiation use efficiency (RUE) of the crop*

Crops sown in different dates and locations are exposed to different solar elevation during the growing season and this may influence PAR as well as RUE due to its effect on radiation transmission. The total PAR value from sowing to maturity was lowest of 246 MJm^{-2} (1991-92) and the maximum value was 284 MJm^{-2} during 1990-91 at Jorhat. At Shayamakhunta it was in the range of 276 MJm^{-2} (1986-87) to 306 MJm^{-2} (1989-90). The RUE of toria (M-27) in terms of economic pod/seed yield at both locations varied moderately yearwise and was in the range of 0.59 gm MJ^{-1} (1986-87) to 0.98 gmMJ^{-1} (1991-92) at Jorhat. At Shayamakhunta the same ranged from 0.08 gm MJ^{-1} (1988-89 to 1990-91) to 0.12 gm MJ^{-1} (1991-92). It was found that the RUE in terms of total biomass yield was in the range of 1.09 gm MJ^{-1} to 1.64 gm MJ^{-1} at different cultivars, plant densities and sowing of mustard (Khichar *et al*., 2000). It was also found that the same for different brassica cultivars ranged from 2.28 gm MJ^{-1} to 2.95 gm MJ^{-1} (Kar and Chakravarty, 1999).

3.4. *Consumptive water use (ET) and water use efficiency (WUE) during the growing period*

The consumptive water use of toria was higher in all the years at Shayamakhunta than that of Jorhat (Table 2). At Shayamakhunta the water use was maximum in 1988-89 (479.5 mm) with mean value of 320.3 mm followed by the crop grown in 1989-90 (347.3 mm). This value ranged from 171.1 mm (1989-90) to 212.3 mm (1986-87) with a mean value of 193.3 mm at Jorhat. It was observed that the consumptive use of water was in the range of 197 to 281 mm at Konkan (Maharashtra) (Jadhav *et al*., 1995). The same was also found in the order of 206.7 to 293.7 mm by Tomar *et al*. (1992).

Analysis of phenophasewise water use revealed the differences in ET at all the phenological stages in each location which is due to different weather conditions during different crop season as well as variations due to soil factors under same cultivars used (M-27 variety of Toria). The mean water use at pod formation and physiological maturity stages at Jorhat is 66.8 mm and 53.3 mm respectively. At Shayamakhunta it was 97.4 mm and 91.7 mm respectively. The variability was found of 10.4% and 11.9 % at Jorhat and 12.4 % and 10.2 % at Shayamakhunta, respectively. The water use at vegetative and flowering stages varied markedly due to variation in duration of growth period, microclimatic conditions and soil differences at both locations (Table 2).

The WUE varies from year to year at same or different locations. At Jorhat it was maximum (12.07 kg/ha/mm) in 1991-92 followed by the crop grown in 1992-93 (11.98 kg/ha/mm). Whereas at Shayamakhunta, it ranged from 1.52 (1991-92) to 0.99 kg/ha/mm (1986-87). The wide variation in WUE may be attributed to the varying environments in different years under both locations. It was found that the WUE was in the range of 3.09 to 3.68 kg/ha/mm for Indian mustard at Konkan

(Maharashtra) (Jadhav *et al*., 1995). The same was also observed in the order of 4.02 to 4.98 kg/ha/mm in Uttar Pradesh (Tomar *et al*., 1992).

4. Conclusions

The following conclusions are drawn :

(*i*) GDD, PTU, HTU, PAR and ET during total growth period of the crop were comparatively higher at Shayamakhunta than that of Jorhat. This is because Shayamakhunta is situated at lower latitude as compared to Jorhat which is responsible for more bright sunshine hours which causes higher values of these parameters.

(*ii*) HUE and RUE also showed high year to year variability at both locations and was higher in early sown crops.

(*iii*) Analysis of phenophasewise GDD, PAR, HTU and PTU also varied with time and space during the growth periods of the crop.

(*iv*) The curvilinear relationship between crop growth duration (days) and GDD during the period from sowing to flowering as well as pod formation to physiological maturity stages respectively showed positive and consistent correlations at both locations.

Acknowledgements

The authors wish to express their sincere thanks to Shri S. K. Banerjee, Deputy Director General of Meteorology, Division of Agricultural Meteorology for providing facilities and encouragement. Thanks are also due to Smt. A. A. Kale for rendering help in carrying out the analysis work.

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