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Thermal growth rate, heat and radiation utilization efficiency of *Brassica* under semiarid environment

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ABSTRACT

Experiments were conducted in two *rabi* seasons to characterise *Brassica* crop growth using thermal based indices and to compute heat and radiation utilization efficiency of three cultivars. *Brassica napus* Cv. B.O.54, *Brassica juncea* Cv. Pusa Bold and *Brassica campestris* Cv. Toria-T9 were sown on three dates at 14-day interval starting from third week of October. Study revealed that the seed filling and maturity stages of crop growth of late sown crop (2nd week of November) experienced 2.5 to 3.0 °C higher temperature as compared to early sown crop (2nd fortnight of October). The heat utilization efficiency varied from 1.01 g m^{-2} $°D^{-1}$ in Cv. Pusa Bold to 0.76 g m^{-2} $°D^{-1}$ in Cv. Toria-T9. Study also revealed that there was significant correlation between thermal growth rate (growing degree days) and crop growth parameters viz., dry biomass, green area index (leaf area index + pod area index) with the correlation coefficient ranging between 0.58 and 0.98 among different cultivars and sowing dates. Study on radiation utilization efficiency (RUE) revealed that in the first crop season it varied from 3.01 g MJ^{-1} in the first sown crop of Cv. Pusa Bold to 2.13 g MJ^{-1} in second and third sowing of Toria-T9. In the second season, the RUE ranged between 3.22 g MJ^{-1} in the first sowing of Pusa Bold and 2.28 g MJ^{-1} in the third sown Toria-T9.

Key words : Brassica species, Heat use efficiency, Radiation use efficiency

The occurrence of different phenological events during growing season of any crop and the effect of temperature on plant growth can be inferred using accumulated heat units (growing degree days, GDD or thermal growth rate). Thermal time has been defined as the independent variable to describe plant growth and development (Dwyer and Stewart, 1986). Termal indices accumulate various combinations of daily temperature above a threshold temperature during the growing season of any crop. The number of degree days required for a crop to progress from one stage to another stage was worked out by several workers in the past. Real time to a given developmental event is approximately linearly related to temperature in the range between a base (T_b) and optimum temperature (Bonhomme *et al.*, 1994).

It is also considered that grain yield is the product of radiation interception, the efficiency of conversion of intercepted radiation to dry matter and partitioning of dry matter to grain.So, a detailed study of radiation interception and its utilization efficiency as influenced by sowing dates and cultivars form an important supplementary component to improve crop yield. The radiation utilization efficiency (RUE i.e., biomass produced per unit radiation) differs from species to species depending upon their leaf area, chlorophyll content and partitioning of biomass etc. In five grain crops maize, sorghum, wheat, rice and sunflower, Kinry *et al.*, (1988) obtained mean values of RUE as 2.2, 2.2, 2.8, 2.8 and 3.5 g MJ^{-1}, respectively.

MATERIALS AND METHODS

The experiment was conducted in two *rabi* seasons (1993-94 and 1994-95) at research station of Indian Agricultural Research Institute, New Delhi (28°35'N, 77°10'E and 288.7 m AMSL). The climate of the station is semiarid with hot dry summers and cold winters. Over the two growing seasons, the general weather parameters are given in Fig. 1 and on the whole it is concluded that maximum temperatures, minimum temperatures, open pan evaporation values, saturation deficit were higher from pod initiation to pod maturity period during first crop season as compared to the second. However, rainfall was higher during second season than in the first.

Three *Brassica* oil seed species (*Brassica napus* Cv. B.O. 54, *Brassica juncea* Cv. Pusa Bold and *Brassica campestris* Cv. Toria-T9) were sown following recommended package of practices. All the species were sown on three dates at 14 days interval starting from third week of October to create different crop growth environments. The experimental plot was laid out in randomized block design with three replications. In order to relate crop growth parameters with temperature based indices, plant samples were collected from each replication and average values of green area index and above ground dry biomass were used. The sum of leaf area and pod area index were considered as green area index since in oilseed crops like *Brassica*, pods occupy a reasonable space for interception of radiation and serve as main assimilating organs in the later stage of the crop growth.

Growing degree day was computed by following formula:

$$GDD = (T_{max} + T_{min})/2 - T_b \text{ °D}$$

where, T_{max} and T_{min} represent the daily maximum and minimum temperatures. T_b is the base temperature below which physiological activities are ceased. For *Brassica* Sps., T_b is considered as 5°C following Morrison *et al.* (1990).

The heat use efficiency (HUE) was computed to compare the relative performance of the different cultivars and treatments with respect to utilization of heat, using the following formula :

$$\text{Heat use efficiency } (g\ m^{-2}\ \text{degree-day}^{-1}) = \frac{\text{Maximum biomass } (g\ m^{-2})}{\text{Accumulated heat units* (degree-day)}}$$

(*corresponding to the day of maximum biomass accumulation)

The values of RUE were computed as :

$$\text{RUE } (g\ MJ^{-1}) = \frac{\text{Maximum above ground dry biomass } (g\ m^{-2})}{\text{Cumulative absorbed PAR* } (MJ\ m^{-2})}$$

(*corresponding to the day of maximum biomass accumulation)

RESULTS AND DISCUSSION

Thermal environment and grain yield

During *rabi* 1993-94 crop season, the grain yield of the three *Brassica* Sps. ranged between 20.1 q ha^{-1} in the first sowing of Pusa Bold to 13.7 q ha^{-1} in the third sowing of Toria-T9. In the cultivar B.O.54, the yield reductions in second and third sowings were 9.8 and 29.4 per cent, respectively over the first sowing of first season, whereas in Pusa Bold, the yield reductions were 12.9 and 23.3 per cent in two late sowings (3rd and 16th November). In the second season also, the yield decreased with delay in sowing by 7.6 per cent in second sowing and 17.4 per cent in the third sowing over the first. In contrast to cultivars B.O.54 and Pusa Bold , the magnitude of reduction of yield due to delayed sowing was marginal in Toria-T9 (Table 1). From ANOVA table, it was found that yield due to late sowing was significantly affected ($P < 0.05$). This could be probably because of relatively higher temperature that prevailed at seed filling and maturity phases of late sown crops. The reductions in total dry weight towards reproductive part in the late sowings might have resulted in lower yields as compared to first sown crop of B.O.54 and Pusa Bold, whereas in cultivar Toria-T9, the yield reductions in late sown crop was not appreciable. Hence, it can be concluded that yield of Toria-T9 was not much affected by short term fluctuations of weather.

Biomass production and heat utilization efficiency

Accumulated heat units to attain different crop growth stages from sowing to maturity for three cultivars and sowing dates are given in Table 2. It is observed from the results that the cultivar B.O.54 recorded higher GDD as compared to Pusa Bold and Toria T-9, reflecting longer duration of cultivar in the different sowings. In all the sowings and cultivars, 1612 to 2550 GDD were accumulated throughout the growing period during *rabi* 1993-94, while in the *rabi* 1994-95 GDD ranged between 1679 and 2445, thus showing the differential varietal response to the requirement of heat units to complete the life cycle. It is also noted that plants in all the sowings of long duration cultivar B.O.54 and medium duration Pusa Bold had accumulated higher GDD in *rabi* 1993-94, because of occurrence of higher temperature during late reproductive phase of this season. In order to express the relationship between growing degree day (GDD) and crop growth parameters (above ground dry biomass production and green area index), regression equations were derived (Table 3). Results revealed that these crop growth parameters were well correlated with the correlation coefficients ranging between 0.58 to 0.98 among different cultivars and sowing dates. These equations may be useful in the algorithm of a crop simulation model to predict *Brassica* crop growth parameters using GDD.

Heat utilization efficiency (HUE) of the three *Brassica* cultivars at maximum biomass accumulation level, as influenced by sowing dates are computed and presented in Table 4. It is observed that cultivar Pusa Bold showed higher HUE for all the sowings and the seasons as compared to B.O.54 and Toria-T9. It may be attributed to higher biomass, green area index in the former than in the later. It is also noted that unlike B.O.54 and Pusa Bold, in the late sown Toria-T9, the reduction of HUE was not significant, probably the biomass production was not affected due to

Table 1: Seed yield (q ha^{-1}) of three *Brassica* Sps. during two *rabi* seasons (1993-94 and 1994-95)

	First sowing		Second sowing		Third sowing	
	1993-94	1994-95	1993-94	1994-95	1993-94	1994-95
B.O.54	17.3	18.3	15.6 (9.8%)	16.9 (7.6%)	12.2 (29.4%)	13.9 (24.1%)
Pusa Bold	20.1	19.5	17.5 (12.9%)	18.0 (7.6%)	15.4 (23.3%)	16.1 (17.4%)
Toria T-9	14.6	15.2	14.5 (0.6%)	14.9 (1.9%)	13.7 (6.1%)	13.9 (8.5%)

(*Values in the parenthesis represent the per cent of reduction of yield over first sowing)

ANOVA : 1993-94 *rabi* season

Source	Sum of squares	D.F.	Mean squares	F Ratio
Sowing dates	72.70	2	36.95	10.62
Cultivars	25.01	2	12.5	3.65
Error	13.61	4	3.42	---
Total	111.4	8	---	---

ANOVA : 1994-95 *rabi* season

Source	Sum of squares	D.F.	Mean squares	F Ratio
Sowing dates	54.83	2	27.41	4.82
Cultivars	45.08	2	22.54	3.96
Error	22.73	4	5.68	---
Total	122.64	8	---	---

late sowings in this cultivar and last sown crop recorded less number of heat units up to maximum biomass level.

Radiation utilization efficiency

The RUE in the three cultivars of *Brassica* as influenced by cultivars and sowing dates during two *rabi* seasons is presented in Table 5. Results reveal that RUE values varied from 3.01 g MJ^{-1} in the first sown crop of Cv. Pusa Bold to 2.13 g MJ^{-1}in the second and third sowing of Toria-T9. In the second season for all the cultivars and sowings RUE ranged between 3.22 g MJ^{-1} in the first sowing of Pusa Bold and 2.28 g MJ^{-1} in the third sown plants of Toria-T9. In both the seasons, it was observed that in Cv. B.O.54 and Pusa Bold the differences of RUE in different sowings were appreciable while variation of RUE was very less in Cv. Toria-T9. The RUE values, obtained in our study on *Brassica* Sps. for two crop seasons are in close agreement with those reported by Kinry *et al.*, (1988) who obtained mean values of RUE of 2.2, 2.2, 2.8, 2.8 and 3.5 g MJ^{-1} in five crops viz., maize, sorghum, wheat, rice and sunflower, respectively.

The seed filling and maturity stages of crop growth of late sown crop (2nd week of November) experienced 2.5 to 3.0°C higher temperature as compared to early sown crop

Table 2: Accumulated heat units (GDD) between sowing and different phenological stages

Phenological Stages	B.O.54			Pusa Bold			Toria-T9		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
1993-94									
Emergence	231	117	115	127	140	115	191	139	99
First Flowering	953	781	700	967	751	523	706	589	497
50% Flowering	1253	1109	958	1120	986	796	874	742	686
90% Podding	1856	1685	1456	1630	1523	1136	1348	1185	1107
End of Seed Filling	1295	2042	1889	2045	1945	1788	1592	1521	1456
Maturity	2550	2392	2172	2392	2255	2170	1822	1727	1612
1994-95									
Emergence	202	141	186	179	141	131	110	119	79
First Flowering	1035	847	699	980	796	679	803	645	552
50% Flowering	1317	1151	990	1204	936	832	996	871	665
90% Podding	1935	1636	1445	1690	1420	1284	1496	1212	1072
End of Seed Filling	2316	2005	1820	2064	1795	1993	1646	1497	1412
Maturity	2445	2210	2049	2345	2137	2104	1964	1725	1679

(2^{nd} fortnight of October). In Cv. B.O.54 and Pusa Bold the delayed sowing caused significant reduction of yield whereas yield reduction in Toria-T9, was not much appreciable because it matures before onset of pre-summer warm conditions.The heat and radiation utilization efficiency was higher in cultivar Pusa Bold as compared to other two cultivars. Study also revealed that there was good correlation between GDD and above ground biomass production and green area index with the correlation coefficient ranging between 0.58 to 0.98 among different cultivars and sowing dates.

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Table 3 : Relationship between growing degree days (GDD) and biomass production and green area index (leaf area index + pod area index)

B.O.54:			
First sowing	:	Biomass = 1.216 (GDD) - 822.15	r=0.950
Second sowing	:	Biomass = 1.185 (GDD) - 938.15	r=0.952
Third sowing	:	Biomass = 1.037 (GDD) - 674.59	r=0.983
Pusa Bold:			
First sowing	:	Biomass = 1.02 (GDD) - 500.159	r=0.893
Second sowing	:	Biomass = 1.727 (GDD) - 809.91	r=0.948
Third sowing	:	Biomass = 0.6580(GDD) - 163.30	r=0.585
Toria-T9:			
First sowing	:	Biomass = 1.38 (GDD) - 1073.23	r=0.982
Second sowing	:	Biomass = 1.22 (GDD) - 773.66	r=0.990
Third sowing	:	Biomass = 1.15(GDD) - 646.41	r=0.981
Relationship between GDD and green area index (GAI):			
First sowing	:	GAI = 0.0041 (GDD) - 1.081	r=0.809
Second sowing	:	GAI = 0.0038 (GDD) - 0.371	r=0.866
Third sowing	:	GAI = 0.0060 (GDD) - 2.275	r=0.973
Pusa Bold:			
First sowing	:	GAI = 0.0087 (GDD) - 7.896	r=0.946
Second sowing	:	GAI = 0.0072 (GDD) - 4.632	r=0.877
Third sowing	:	GAI = 0.0.0088(GDD) - 4.849	r=0.971
Toria-T9:			
First sowing	:	GAI = 0.0033 (GDD) - 1.6239	r=0.895
Second sowing	:	GAI = 0.0060 (GDD) - 3.369	r=0.968
Third sowing	:	GAI = 0.0016(GDD) - 2.18	r=0.932

Table 4 : Heat utilization efficiency of three *Brassica* cultivars

Treatments	Heat units at maximum biomass level (°C)		Maximum biomass		Heat utilization efficiency ($g\ m^{-2}\ {}^{\circ}D^{-1}$)	
	I	II	I	II	I	II
1st Sowing	1806	1935	1690	1852	0.93	0.95
2nd Sowing	1785	1889	1635	1766	0.92	0.93
3rd sowing	1617	1583	1361	1473	0.84	0.91
Pusa Bold						
1st Sowing	1708	1802	1815	1976	1.06	0.09
2nd Sowing	1696	1695	1684	1696	0.99	1.01
3rd sowing	1572	1623	1460	1531	0.92	0.94
Toria-T9						
1st Sowing	1592	1696	1206	1293	0.75	0.76
2nd Sowing	1521	1541	1168	1275	0.76	0.82
3rd sowing	1456	1448	1165	1187	0.82	0.84

I : Crop growth season 1993-94 II : crop growth season 1994-95

Table 5 : Radiation utilization efficiency (RUE) in three *Brassica* cultivars during *rabi* 1993-945 (I) and 1994-95 (II)

	PAR at maximum biomass level (MJ m^{-2})		Maximum biomass (g m^{-2})		RUE (g MJ^{-1})	
	I	II	I	II	I	II
1st Sowing	622	655	1690	1852	2.72	2.82
2nd Sowing	578	599	1635	1766	2.83	2.95
3rd sowing	544	562	1361	1473	2.50	2.62
Pusa Bold						
1st Sowing	603	612	1815	1976	3.01	3.22
2nd Sowing	572	578	1684	1696	2.94	2.94
3rd sowing	601	622	1460	1531	2.43	2.46
Toria-T9						
1st Sowing	558	562	1206	1293	2.16	2.30
2nd Sowing	546	502	1168	1275	2.13	2.54
3rd sowing	548	521	1165	1187	2.13	2.28

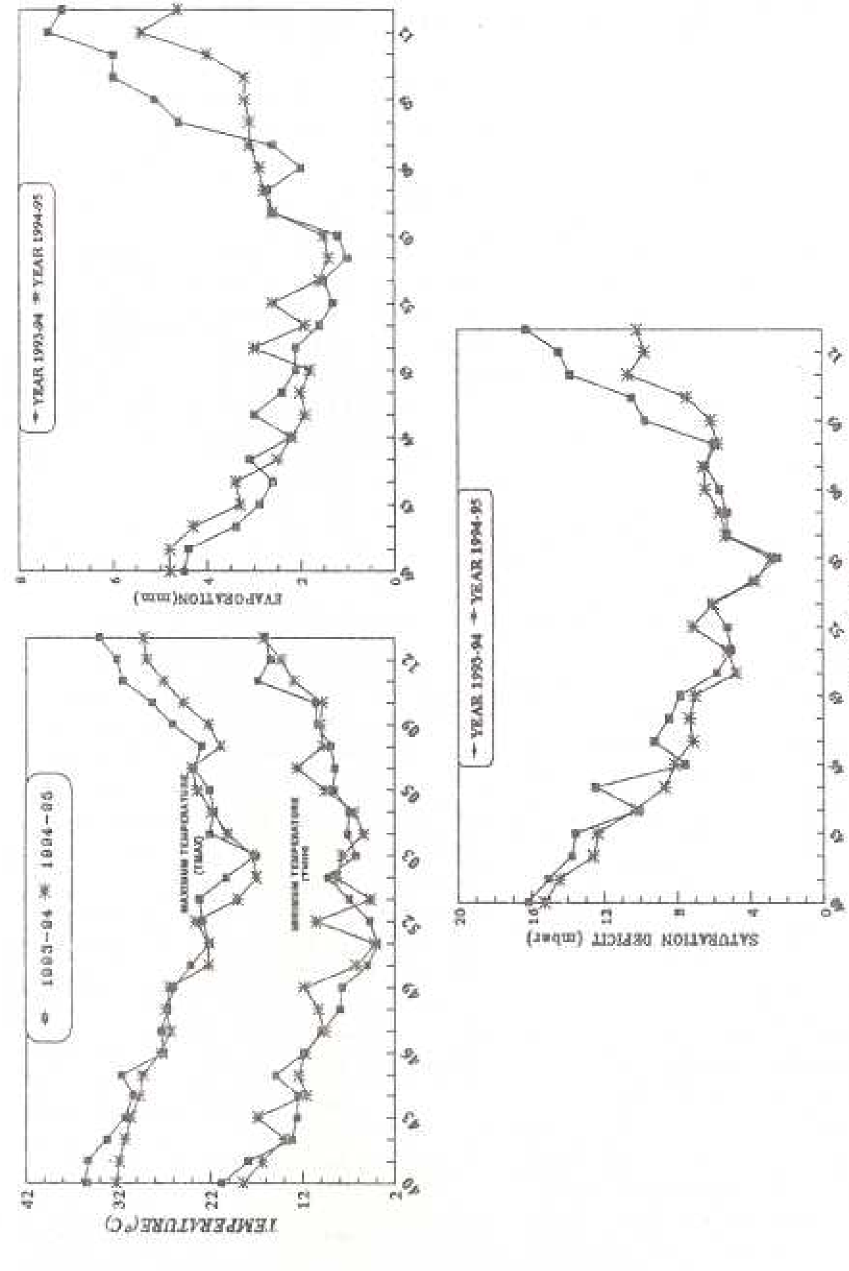

Fig.1 Temperature, evaporation and satuaration deficit during two crop seasons