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Thermal Requirement, Heat and Radiation Use Efficiency of *Kharif* Soybean in Middle Gujarat Region as Influenced by Cultivars and Plant Geometry

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present study proposes to measure the thermal requirements, heat and radiation use efficiency of *kharif* soybean cultivars (NRC 37, GS 1 and GS 2) in the central region of Gujarat. The findings of study conclude that among all the different geometry 30 x 10 cm produced highest seed (4403 kg/ha) and total biomass yield (5818 kg/ha) over the other two spacing because higher heat use efficiency (heat use efficiency (HUE) for Growing degree day (GDD)- 0.69 kg/ha/°C Day; HUE for

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Heliothermal units (HTU) - 0.14 kg/ha/°C Day hour; HUE for Photothermal units (PTU) - 0.05 kg/ha/°C Day hour). The cultivar NRC 37 (4415 kg/ha) produced highest seed yield followed by GS 1 (3799 kg/ha) and GS 2 (3670 kg/ha). Heat unit requirement of cultivar NRC 37 (GDD - 1952°C Day; HTU – 9894°C Day hour; PTU-25974°C day hour) was more as compared to GS 2 (GDD - 1951°C day; HTU – 9893°C day hour; PTU-25973°C day hour) and GS 1 (GDD - 1931°C day; HTU – 9809°C day hour; PTU-25681°C day hour), respectively. The radiation use efficiency (RUE) for seed yield and biomass are more in 45 x 5 cm geometry.

Keywords: Soybean; GDD; HTU; PTU; HUE and RUE.

1. INTRODUCTION

Soybean (*Glycine max* L. Merrill) is an important oilseed crop and a very rich source of protein (40-45%). Since the Saurashtra region saw extremely severe rainfall in 2020, which entirely destroyed groundnut production and caused groundnut seed prices to rise to levels that were out of reach for marginal and small farmers, *kharif* soybean cultivation has seen a significant expansion in Gujarat. In 2019, 1.006 lakh hectares of soybeans were cultivated; in 2022, that number would rise to 2.216 lakh hectares [1]. Soybean is generally quite sensitive to photoperiod and its flowers in response to shortening of the dark period. The crop requires 110-120 days from sowing to maturity. The duration of a particular stage of growth was directly related to temperature because plants required a specific amount of accumulated heat to develop into upcoming growth stage and this duration for particular species could be predicted using the sum of daily air temperatures-based indices [2]. Thus, air temperature-based indices like growing degree days (GDD), Photothermal units (PTU), Heliothermal units (HTU), Heat use efficiency (HUE) etc. can successfully be used for describing phenological behavior and other growth parameters like leaf area development, biomass production, seed yield, oil content etc. in relative terms [3]. Heat and radiation use efficiencies in term of dry matter accumulation or yield are important aspects, which have great practical application. The experiment was conducted to find out the thermal requirement of given soybean cultivars and also find the impact of plant geometry on heat and radiation use efficiency.

2. MATERIALS AND METHODS

The present investigation for soybean cultivars under varying plant spacing in middle Gujarat condition was conducted during the *kharif* season of 2015 and 2016 at research Farm, B. A. College of Agriculture, AAU, Anand, Gujarat. The experiment was laid out in a split plot design placed after the land preparation with three plants spacing (S_1 - 45 x 10 cm, S_2 - 45 x 5 cm and S_3 - 30 x 10 cm) and three varieties (NRC 37 (Ahilya-4) (V_1), Gujarat Soybean 1 (GS 1) (V_2) and Gujarat Soybean 2 (GS 2) (V_3)) were allotted as sub plot treatments. The treatments were replicated four times and assigned at random to each main and subplot in each replication respectively. The growth of soybean was divided into eight different phenophases *viz.,* emergence – branching (P1), branching-first flowering (P2), first-50 % flowering (P3), 50 % -100 % flowering (P4), 100 % flowering-pod formation (P5), pod formation - 50 % pod formation (P6), 50% -100 % pod formation (P7) and 100 % pod formation-physiological maturity (P8). Agrometeorological indices like Growing degree days (GDD), Heliothermal unit (HTU), Photothermal unit (PTU) were computed using weather data and methodology as given below.

The GDD was calculated by the average daily temperature which is subtracted from the base temperature. The base temperature taken for the soybean crop was 10 ℃. The HTU was calculated by GDD multiplied by actual sunshine hours and PTU was calculated by GDD to multiply with maximum possible sunshine hours and totalize each day GDD, HTU, and PTU in accordance with the crop maturity days to find total accumulated requirement units of GDD, HTU and PTU to complete crop life cycle in given environment. The heat use efficiency (HUE) was calculated by total seed yield (kg ha^{-1}) divided by total accumulated GDD.

3. RESULTS AND DISCUSSION

3.1 Growing Degree Days (GDD)

GDD required for the completion of the crop growth stages of three cultivar from sowing to maturity of crop as attended by different cultivars and years are given in Table 1 and depicted in Fig. 1. Result revealed that the GDD under different phenophases from emergence to physiological maturity was highest in V_3 cultivars. Maximum GDD accumulated from emergence to branching phase was in V_3 cultivars followed by V_2 and V_1 in emergence – Branching (P1) phase, First - 50 % flowering (P3), 50 % -100 % flowering (P4) and 100 % pod formation-physiological maturity (P8) phase for both the years. The GDD in the year 2015 was greater (1968 °C Day) as compare to GDD in the year of 2016 (1937 °C Day) in V_3 cultivar. It is might be due to temperature range of 2015 was greater compared to 2016. Moreover, due to adequate rainfall and less sunshine received adequate environmental condition which was favorable for development of most sensitive phases. As a result of this the yield of 2016 was more as compared to 2015. The average heat unit requirement of cultivar V_1 was 1951 °C day, cultivar V_2 required 1931°C day and cultivar V_3 required 1952 °C day. The results are in good agreement with Manish Bhan et al., [4].

3.2 Heliothermal Units (HTU)

Heliothermal units (HTU) accumulated during each phase of soybean crop cultivars and years are given in Table 2 and depicted in Fig. 2. Results revealed that HTU was maximum under 2015 as compared to 2016 It is might be due to the bright sunshine hours and temperature were more in all the phases from emergence to physiological maturity. Among the cultivars maximum HTU accumulated by V_3 cultivars followed by V_2 and V_1. During branching-first flowering (P2) and 100 % flowering-pod formation (P5) phase (2016) less HTU was accumulated due to the less or negligible bright sunshine hours were received as mostly cloudy weather was there. In V_3 cultivars maximum HTU was obtained as compared to V_2 and V_1 in 2015 followed by 2016 from emergence to physiological phase. HTU requirement V_1 and V_3 are 9893°C Day hour and 9894 °C Day hour, while V_2 required 9809 °C Day hour to complete life cycle. The results are in good agreement with Usha and Jadhav [5].

3.3 Photothermal Units (PTU)

Photothermal units (PTU) accumulated during each phase of soybean crop as attended by different cultivars and years are given in Table 3 and depicted in Fig. 3. Results revealed that photothermal units (PTU) were maximum under 2015 as compared to 2016. Variation in PTU during different phases was similar to that observed in case of GDD under different cultivars. Among the cultivars minimum PTU accumulated by V_3 cultivars followed by V_2 and V_1. PTU requirement V_1 and V_3 are 25973 °C Day hour and 25974 °C Day hour, respectively while V_2 required 25681 °C Day hour to complete life cycle. This result showed good line with finding of Kaushik et al., [6] and Chavan et al., [7].

3.4 Heat Use Efficiency (HUE)

The quantification of the heat use efficiency in terms of dry matter production per unit of growing degree day (GDD), heliothermal unit (HTU) and photothermal unit (PTU) are important for determination of the soybean yield potential in the different environment during growing period of the soybean crop in year of 2015 and 2016. The heat use efficiency (HUE) was worked out for the treatments of different plant spacing and cultivars sown crop and years are given in Table 4. The study of HUE of grain yield showed that the HUE decreased with advancement of the age of crop. The results also showed that the HUE of overall growth period was found more in 2016 followed by 2015 in cultivar NRC 37 in V_3 (0.78-0.75 kg/ha/°C days), followed by GS 1 V_2 (0.65-0.60 kg/ha/°C Day) and GS 2 V_1 (0.57-0.55 kg/ha/°C Day). Under plant spacing S3 (0.70-0.69 kg/ha/°C Day) has high HUE as compared to S2 (0.67-0.62 kg/ha/°C Day) and S1 (0.62-0.60 kg/ha/°C day) for seed yield. Similar trend is found in the case of HUE for HTU and PTU. This result in good accordance with finding of Tupe et al., [8].

3.5 Heat Use Efficiency (HUE) for Biomass

The heat use efficiency (HUE) was worked out on the basis of total dry biomass for the treatments of different plant spacing and cultivars sown crop and years are given in the Table 5. The study of HUE of biomass yield showed that the HUE was more in 2016 as compared to 2015 with advancement of the age of crop. The results also showed that the HUE of overall growth period was found more in 2016 followed by 2015 in cultivar NRC 37 in V_3 (3.0 - 2.9 kg/ha/°C Day) followed by GS 1 V_2 (0.69-0.48 kg/ha/°C Day) and GS 2 V_1 (2.4 - 2.3 kg/ha/°C Day). Among different plant spacing S_3 (2.9 -2.8 kg/ha/°C Day) has high HUE as compared to S_2 (2.6-2.5 kg/ha/°C Day) and S_1 (2.4-2.3 kg/ha/°C Day) for biomass. Similar trend is found in the case of HUE for HTU and PTU.

3.6 Radiation Use Efficiency (RUE)

RUE of different soybean cultivars in two crop seasons and growth periods between emergence to harvesting under different plant spacings are presented in Table 6. The relation between solar radiation and dry matter production is useful for judging the potential of crop to harvest solar energy. The highest RUE for seed yield was obtained in S_2V_3 (0.45 g MJ/m^2 and 0.59 g MJ/m^2) treatment followed by other treatments combinations in both the years. In case of lowest RUE for biomass yield were found in S_1V_1 (0.99 g MJ/m^2) in 2015 and S_1V_2 (1.32 g MJ/m^2) in 2016 years of experiment. Maximum RUE for seed and biomass yield were in S_2 (45 X 5 cm) plant spacing and NRC 37 (V_3) cultivar among all the treatments and their combination in both the years. The results are in good agreement with Kumar et al., [9].

Table 1. Phase-wise growing degree days (GDD) influenced by different cultivars of soybean crop during *kharif* 2015 and 2016

Phenophases	GDD (°C Day)					
	V_1		V_2		V_3	
	2015	2016	2015	2016	2015	2016
Emergence – Branching (P_1)	718	624	698	639	736	642
Branching-first flowering (P_2)	57	35	97	37	58	36
First-50 % flowering (P_3)	207	232	168	232	207	232
50 % -100 % flowering (P_4)	153	111	113	90	114	109
100 % flowering-pod formation (P_5)	79	122	98	48	116	86
pod formation - 50 % pod formation (P_6)	151	144	209	220	191	201
50% -100 % pod formation (P_7)	160	175	181	177	208	193
100 % pod formation- physiological maturity (P_8)	444	493	384	473	337	439
Crop cycle	1967	1936	1947	1916	1968	1937
Average crop cycle	**1951**		**1931**		**1952**	

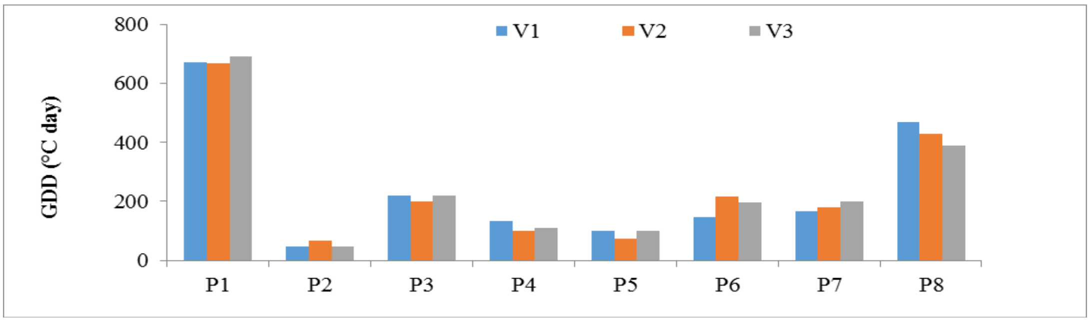

Fig. 1. Phase-wise Growing degree days (GDD) influenced by different cultivars of soybean crop during *Kharif* 2015 and 2016

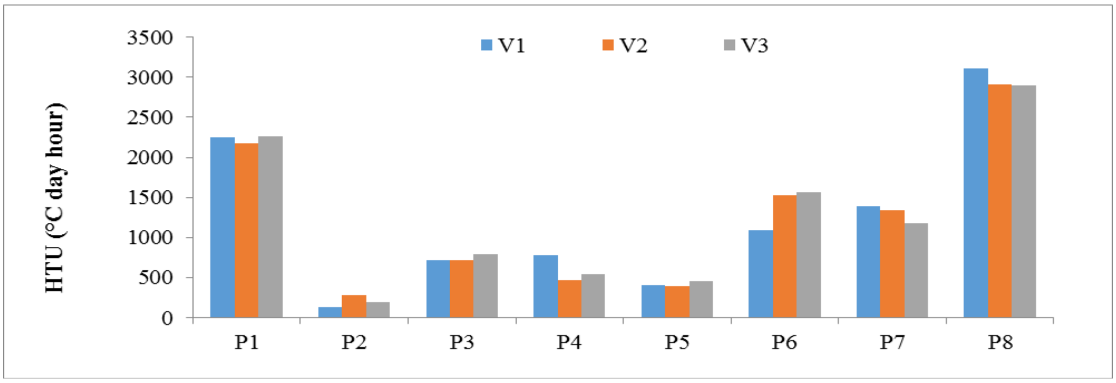

Fig. 2. Phase-wise heliothermal unit (HTU) influenced by different cultivars of soybean crop during *Kharif* 2015 and 2016

Table 2. Phase-wise heliothermal unit (HTU) influenced by different cultivars of soybean crop during *Kharif* 2015 and 2016

Phenophases	HTU (°C Day hour)					
	V_1		V_2		V_3	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**
Emergence – Branching (P_1)	2890	1618	2803	1537	2911	1618
Branching-first flowering (P_2)	256	0	407	166	329	73
First-50 % flowering (P_3)	821	613	670	772	908	672
50 % -100 % flowering (P_4)	1094	465	790	140	752	333
100 % flowering-pod formation (P_5)	601	223	774	7	782	138
pod formation - 50 % pod formation (P_6)	1248	942	1743	1314	1795	1336
50% -100 % pod formation (P_7)	1278	1507	1223	1449	1025	1327
100 % pod formation- physiological maturity	3474	2755	3166	2657	3161	2627
Crop cycle	11664	8123	11577	8041	11665	8124
Average crop cycle	**9893**		**9809**		**9894**	

Table 3. Phase-wise photo-thermal unit (PTU) influenced by different cultivars of Soybean crop during Kharif 2015 and 2016

Phenophases	PTU (°C day hour)					
	V_1		V_2		V_3	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**
Emergence – Branching (P_1)	11332	8235	11028	8414	11581	8466
Branching-first flowering (P_2)	780	459	1296	481	783	468
First-50 % flowering (P_3)	2841	2971	2325	2968	2849	2966
50 % -100 % flowering (P_4)	2132	1401	1635	1130	1620	1372
100 % flowering-pod formation (P_5)	1074	1523	1308	598	1572	1076
pod formation - 50 % pod formation (P_6)	1984	1779	2754	2724	2469	2474
50% -100 % pod formation (P_7)	1828	2129	2007	2143	2484	2327
100 % pod formation- physiological maturity (P_8)	5686	5793	5000	5553	4299	5140
Crop cycle	27657	24290	27353	24010	27658	24291
Average crop cycle	**25973**		**25681**		**25974**	

Table 4. Heat use efficiency (HUE) of seed yield for soybean cultivars for different plant spacing using the GDD, HTU and PTU

Treatments	HUE (GDD) (kg/ha/°C day)		HUE (HTU) (kg/ha/°C day hour)		HUE (PTU) (kg/ha/°C day hour)	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**
S_1 (45 x 10 cm)	0.60	0.62	0.10	0.14	0.04	0.05
S_2 (45 x 5 cm)	0.62	0.67	0.10	0.15	0.04	0.05
S_3 (30 x 10 cm)	0.69	0.70	0.12	0.16	0.05	0.06
V_1 (GS 2)	0.55	0.57	0.09	0.13	0.04	0.04
V_2 (GS 1)	0.60	0.65	0.10	0.15	0.04	0.05
V_3 (NRC 37)	0.75	0.78	0.12	0.18	0.05	0.06

Table 5. Heat use efficiency (HUE) of biomass yield of soybean crops under varying plant spacing and varieties using the GDD, HTU and PTU

Treatments	HUE (GDD) (kg/ha/°C day)		HUE (HTU) (kg/ha/°C day hour)		HUE (PTU) (kg/ha/°C day hour)	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**
S_1 (45 x 10 cm)	2.3	2.4	0.38	0.55	0.16	0.19
S_2 (45 x 5 cm)	2.5	2.6	0.42	0.60	0.18	0.21
S_3 (30 x 10 cm)	2.8	2.9	0.47	0.66	0.20	0.23
V_1 (GS 2)	2.3	2.4	0.39	0.54	0.17	0.19
V_2 (GS 1)	2.4	2.6	0.41	0.59	0.17	0.20
V_3 (NRC 37)	2.9	3.0	0.48	0.69	0.20	0.24

Table 6. Radiation use efficiency (RUE) of seed and biomass yield of soybean crops under varying plant spacing and varieties

Treatments	2015			2016		
	IPAR (MJ/m^2)	Seed (RUE) (g MJ/m^2	Biomass (RUE) (g MJ/m^2	IPAR (MJ/m)	Seed (RUE) (g MJ/m^2	Biomass (RUE) (g MJ/m^2
S_1V_1	899	0.22	0.99	596	0.35	1.50
S_1V_2	776	0.30	1.16	702	0.33	1.32
S_1V_3	837	0.30	1.25	686	0.36	1.55
S_2V_1	621	0.37	1.45	398	0.58	2.33
S_2V_2	520	0.44	2.03	509	0.53	2.09
S_2V_3	659	0.45	1.49	528	0.59	2.13
S_3V_1	994	0.25	0.99	709	0.35	1.57
S_3V_2	896	0.29	1.29	761	0.37	1.58
S_3V_3	998	0.33	1.34	799	0.41	1.70

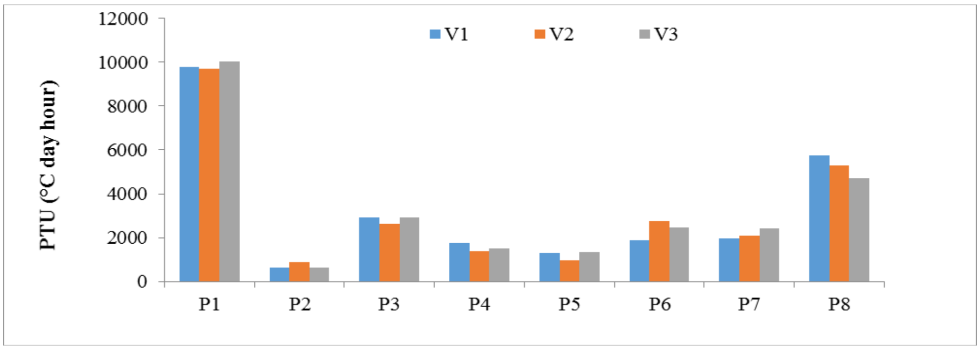

Fig. 3. Phase-wise photo-thermal unit (PTU) influenced by different cultivars of Soybean crop during Kharif 2015 and 2016

4. CONCLUSION

The efficiencies of heat and radiation use in terms of dry matter accumulation or yield are aspects that have a great practical application for crops. The current study has found that crop yield of soybean varieties is impacted by both temperature and the number of hours of sunshine. The crop needs a precise amount of accumulated heat units, which can change from year to year. The heat and radiation use efficiency were affected by plant geometry and it's varied with cultivars but plant geometry has no impact on thermal requirements of crop.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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