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Assessment of thermal indices of soybean under different sowing dates

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Abstract

A field experiment was conducted at the Department of Agronomy, Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, during the *kharif* season of 2024 to investigate crop coefficient, growing degree days (GDD), photo-thermal units (PTU), and helio-thermal units (HTU) for soybean (*Glycine max* [L.] Merrill). The experiment followed a split-plot design with three replications and included two factors: three sowing dates D₁ (SMW 25), D₂ (SMW 26), and D₃ (SMW 27) and four soybean varieties: V₁ (JS 93-05), V₂ (MAUS 612), V₃ (MAUS 725), and V₄ (MAUS 731). Each treatment was sown with a spacing of 45 × 5 cm, total 12 treatments across 36 plots. The gross layout measured 5.4 × 4.5 m, with each net plot sized at 4.5 × 4.1 m. The study aimed to determine the duration of phenological stages, quantify thermal requirements, and assess the application of thermal indices in predicting soybean development. Results revealed that the highest accumulation of GDD (2569.6 °C days), HTU (11303.6 °C days hrs.), and PTU (20157.0 °C days hrs.) was observed under D₂ (SMW 26). In contrast, the lowest values were recorded under D₃ (SMW 27), with GDD at 2299.2 °C days, HTU at 9024.9 °C days hrs., and PTU at 18125.8 °C days hrs.

Keywords: GDD, PTU, HTU, sowing dates, thermal indices

Introduction

Crop productivity is significantly influenced by climatic conditions, with temperature, photoperiod, and solar radiation playing key roles in determining growth and yield outcomes. Soybean (*Glycine max* L. Merrill), a widely cultivated leguminous crop, has the ability to grow across diverse agro-climatic zones. However, its yield potential is highly sensitive to prevailing weather conditions throughout its growth period. Being a short-day plant, soybean exhibits marked responses to changes in temperature and day length, which directly affect its phenological development and yield formation.

Among various climatic factors, temperature is particularly critical as it governs the timing of sowing and progression through different phenophases such as germination, flowering, pod development, and maturity. An accurate understanding of these developmental stages and their environmental requirements is essential for optimizing yield.

Crop growth and development largely depend on the amount of energy received and the thermal environment during the growing season. Among the major crops of the region, soybean is a classic short-day and thermo-sensitive plant. The environmental conditions experienced by the crop can be altered by adjusting the sowing dates, which expose the crop to different climatic situations throughout its growth period. Variations in sowing time therefore lead to differences in crop performance and productivity due to changes in crop-environment interactions.

To understand how a crop responds to the weather conditions it experiences at various growth stages, it is essential to analyze its phenotypic plasticity and yield in relation to these environmental factors. The present study aims to quantify the crop's growing environment in terms of the natural weather conditions prevailing during different phenophases, in order to evaluate crop responses with respect to phenology, accumulated heat units, yield, and heat use efficiency.

Agrometeorological indices such as Growing Degree Days (GDD), Photo-Thermal Units (PTU), Helio-Thermal Units (HTU), serve as reliable tools to quantify the crop's response to climatic variables.

These indices provide insights into the thermal and radiation use patterns of soybean during its growth cycle and help in evaluating the influence of weather parameters on crop performance. Therefore, integrating these agrometeorological tools is crucial for improving soybean productivity under variable climatic conditions

Materials and Methods

The field experiment was conducted at experimental farm, Department of Agronomy, College of agriculture, VNМКV Parbhani (M.S) during *kharif* 2024. The site was located 19°16' North latitude and 76°47' East longitude and at 409 altitudes above mean sea level and has a semi-arid climate. The experiment was laid out in Split plot design (SPD) with 3 main plot of sowing dates and 4 sub plot of four varieties with 3 replications. The experiment consist of 3 sowing dates D₁ (SMW 25), D₂ (SMW 26), D₃ (SMW 27) and 4 different varieties V₁ (JS 93-05), V₂ (MAUS 612), V₃ (MAUS 725), V₄ (MAUS 731). The gross plot size was 5.4 m x 4.5 m and net plot size was 4.5 m x 4.1 m. The soil of experimental site was black loamy. Plant protection measures were taken as per the recommended schedule.

Phenological Stages	Description
P1	Sowing to emergence
P2	Emergence to seedling
P3	Seedling to branching
P4	Branching to flowering
P5	Flowering to pod formation
P6	Pod formation to grain formation
P7	Grain formation to pod development
P8	Pod development to pod containing full size grain
P9	Pod containing full size grain to dough stage
P10	Dough stage to maturity

Growing Degree Days (GDD)

Growing Degree Days (GDD) were estimated by summing the daily mean temperatures that exceeded the base temperature threshold of 10 °C, which is considered optimal for soybean development. The cumulative GDD was obtained through the daily addition of these temperature values. The GDD for each day was calculated using the following formula: (Freeland *et al.* 2017) [2].

$$\text{Growing degree days} = \sum \frac{(T_{\max} + T_{\min})}{2} - T_b$$

Where,

T_{max} = Daily maximum temperature

T_{min} = Daily minimum temperature

T_b = Minimum threshold/Base temperature

Photo-thermal units (PTU)

The photothermal units (PTU) for a day represented by the product of GDD and the maximum possible sunshine hours (day length) for that day. The accumulated PTU for a particular phenophase was calculated as follows:

- Accumulated PTU = Σ (GDD × Day length)

Helio-thermal units (HTU)

Helio-Thermal Units (HTU) for a given day are calculated by multiplying the Growing Degree Days (GDD) with the number of actual bright sunshine hours recorded on that day. The total HTU accumulated during specific phenological stages was obtained using the following formula:

- Accumulated HTU = Σ (GDD × Bright sunshine hours)

Result and Discussion

Weather parameters such as (RF), bright sunshine hours (BSS), maximum (T max.), minimum (T min.), and mean (T mean) temperatures, morning (RH), afternoon (RH), and mean (RH mean) relative humidities, and agro-meteorological indices such as accumulated growing degree days (Accu. GDD), accumulated photo thermal unit (Accu. PTU), and accumulated helio-thermal unit (Accu HTU) (Kumar *et al.*, 2008) [7].

The performance of seed and Stover yield was evaluated phase by phase in terms of seed yield and total biomass, together with the corresponding weather parameters and agro-meteorological indices (Shah and Hanta, 1989) [10].

Weather conditions during the crop season (2024-25)

The weekly meteorological data recorded at the Agrometeorological Observatory, V.N.M.K.V., Parbhani for the soybean growing season (2024-25) are presented in Table 1. The data indicate that the crop experienced a total rainfall of 868.5 mm distributed over 43 rainy days during the season. The mean maximum temperature was 31.88 °C, while the mean minimum temperature was 22.51 °C. Relative humidity ranged between 89.52% (RH-I) and 60.76% (RH-II), with an average bright sunshine hour (BSS) of 4.97 hours per day.

During the early sowing period, moderate rainfall (19.0-66.4 mm) accompanied by relatively high maximum temperatures (34.2-34.5 °C) and sufficient sunshine (5.5-6.3 hrs) created favorable thermal conditions for soybean germination and early vegetative growth. The SMW 26 (25 June-01 July) recorded 29.4 mm of rainfall and 5.5 hours of bright sunshine, which provided optimum soil moisture and radiation balance, supporting better crop establishment compared to the preceding or subsequent weeks.

A gradual decline in temperature and bright sunshine hours was observed during later weeks (27-30 SMW), coinciding with increased humidity and intermittent rainfall, which favored vegetative growth but occasionally resulted in cloudy conditions. The reproductive phase coincided with adequate rainfall and moderate temperatures (30-32 °C), conducive to flowering and pod development. Toward crop maturity (39-44 SMW), rainfall sharply decreased with relatively higher sunshine hours (7-8 hrs), aiding in the proper drying of pods and seed maturation.

Growing Degree Days (GDD)

Table 2 indicates that the accumulation of growing degree days (GDD) during each phenophase was calculated using a base temperature of 10 °C, resulting in an overall average of 2441.7 °C days. The data reveal that sowing date had a significant influence on GDD accumulation. The highest GDD was recorded for sowing during the SMW 26, reaching 2569.6 °C days, followed by 2456.5 °C days in the SMW 25, and 2299.2 °C days in the SMW 27. Among the different phenophases, the emergence to seedling stage (P₂) showed the greatest GDD accumulation with a mean of 711.6 °C days, whereas the branching to flowering stage (P₄) required the least, with only 98.1 °C days. These findings align with the results of Karunakar A.P *et al.* (2018) [5] Gadhave, R. S *et al.* (2023) [3] and Kale *et al.* (2024) [4], who also reported higher GDD accumulation in the SMW 26 compared to other treatments.

Helio-thermal Units (HTU)

According to the data presented in Table 3, the helio-thermal units (HTU) required during each phenophase varied depending on the sowing date. The average HTU across all sowing dates (D₁, D₂ and D₃) was recorded as 10,458.9 °C day hrs. Among these, the highest HTU was observed for the crop sown in the SMW 26, amounting to 11,303.6 °C day hours. In contrast, the lowest HTU was recorded for the SMW 27 sowing (D₃), with a value of 9,024.9 °C day hrs. This reduction can be attributed to variations in temperature and the availability of bright sunshine hours during the crop's growth cycle. Similar result observed by Gadhave, RS, *et al.* (2023) ^[3].

Photo-thermal unit (PTU)

Table 4 presents the photo-thermal unit (PTU) values accumulated by the crop throughout its growth across different phenophases and sowing dates. PTU accumulation was influenced by the number of days taken to complete each phenophase, the growing degree days, and the day length experienced by the crop. The results indicate a significant variation in PTU accumulation based on sowing dates. On average, 19,243.1 °C day hours were accumulated across all sowing times. The highest mean PTU was recorded in the SMW 26 (20,157.0 °C day hrs), followed by the SMW 25 (19,446.6 °C day hrs), while the lowest was recorded in the SMW 27 (18,125.8 °C day hrs). Consistently, the SMW 26 sowing recorded the highest PTU across all phenophases, whereas the SMW 27 sowing recorded the lowest. Among the phenological stages, the emergence to seedling stage (P₂) accumulated the highest PTU, whereas the branching to flowering stage (P₄) showed the lowest accumulation across all sowing dates. These findings align with the results of Karunakar A.P *et al.* (2018) ^[5] Gadhave, R. S *et al.* (2023) ^[3] and Kale *et al.* (2024) ^[4].

Yield

The crop sown during SMW 26 (D₂) produced significantly higher seed, straw, and total biological (seed + straw) yields. Which was statistically at par with SMW 25 (D₁) in terms of both seed and biomass yield (Table 5). In contrast, sowing during SMW 27 (D₃) resulted in the lowest values for all yield parameters. The superior performance of the crop sown in SMW 26 (D₂) can be attributed to the presence of adequate rainfall and moisture availability throughout the vegetative and reproductive growth phases, along with more favorable thermal and photoperiodic conditions compared to other sowing dates. In later sowings, the crop was subjected to reduced soil moisture during vegetative growth and shorter photoperiods, especially during the crucial stages of pod formation and seed development.

Earlier studies also support these findings. Matsul and Nishiiri (1982) ^[8] observed that delayed sowing reduced dry matter accumulation per plant. Similarly, Anil Kumar *et al.* (2008) ^[1] also reported that early sowing (June 16) led to higher dry matter accumulation, seed yield, and stover production due to the availability of more growing degree days. These observations align with the results of Mengxuan Hu and Pawel Wiatrak (2011) ^[9] and Kathmale *et al.* (2013) ^[6]. Although later sowings experienced more sunshine hours towards the end of the crop period, the plants were unable to effectively utilize this due to limited growth potential and shortened durations of key developmental stages. The reduction in the length of these growth phases in late sowings likely contributed to the decline in total biomass production, a trend also supported by the findings of Kathmale *et al.* (2013) ^[6]. Regarding varietal performance, V₂ (MAUS 612) produced a significantly higher seed yield than V₁ (JS 93-05) and V₃ (MAUS 725), and was statistically comparable to V₄ (MAUS 731). For straw and total biological yield, V₂ (MAUS 612) and V₄ (MAUS 731) performed similarly and recorded higher biomass production than V₁ (JS 93-05) and V₃ (MAUS 725).

Table 1: Weekly weather data recorded during crop season (2024-25) recorded at Agro meteorological observatory V.N.M.K.V. Parbhani

SMW	Period	RF (mm)	Rainy days (No)	Temperature °C		Humidity (%)		BSS (Hrs.)
				Max.	Min.	RH-I	RH-II	
24	11-17 Jun	66.4	3	34.5	23.5	88	53	6.0
25	18-24 Jun	19.0	2	34.2	24.1	85	55	6.3
26	25-01 Jul	29.4	2	33.5	24.2	82	57	5.5
27	02-08 Jul	52.7	3	33.1	23.5	85	61	4.2
28	09-15 Jul	05.4	1	31.4	23.5	86	68	3.7
29	16-22 Jul	59.0	5	29.2	23.0	94	80	0.3
30	23-29 Jul	58.2	5	27.6	22.8	93	81	0.0
31	30-05 Aug.	09.8	5	30.7	23.2	90	68	1.6
32	06-12 Aug.	22.0	3	31.0	22.7	91	65	3.4
33	13-19 Aug	02.3	0	32.1	23.8	91	68	4.3
34	20-26 Aug	131.4	2	30.9	22.7	95	68	4.0
35	27-02 Aug	165.0	2	30.4	21.8	92	74	4.8
36	03-09 Sep.	35.7	2	30.1	22.3	92	68	5.1
37	10-16 Sep.	0.2	0	31.5	21.2	89	56	6.0
38	17-23 Sep.	91.1	2	32.3	21.8	91	61	5.6
39	24-30 Sep	59.8	2	31.5	22.8	92	64	4.9
40	01-07 Oct.	01.7	0	34.1	23.1	89	47	8.1
41	08-14 Oct.	09.4	1	32.9	22.4	88	52	8.3
42	15-21 Oct.	42.7	2	33.0	22.0	90	55	7.4
43	22-28 Oct.	07.3	1	32.0	19.2	90	38	7.7
44	29-04 Nov	0.0	0	33.5	19.3	87	37	7.3
Mean		868.5	43	31.88	22.51	89.52	60.76	4.97

Table 2: Phenophase wise GDD required for different sowing dates of soybean

Treatment	Phenophases of soybean										Total	Mean
	P ₁	P ₂	P ₃	P ₄	P ₅	P ₆	P ₇	P ₈	P ₉	P ₁₀		
Sowing dates												
D ₁ -SMW25	134.9	739.4	128	93.8	178.5	152	157.2	232	329.3	311.4	2456.5	245.65
D ₂ -SMW26	131.4	737.3	177.4	125.3	185	177.8	146.1	172.8	255.1	461.4	2569.6	256.96
D ₃ -SMW27	127.5	658.3	125.3	75.2	99.8	125.8	94.8	194.5	310.3	487.7	2299.2	229.92
Mean	131.26	711.66	143.56	98.1	154.43	151.43	132.7	199.76	298.23	420.16	2441.76	244.17

Table 3: Phenophase wise Helio Thermal Unit required for different sowing dates of soybean

Treatment	Phenophases of soybean										Total	Mean
	P ₁	P ₂	P ₃	P ₄	P ₅	P ₆	P ₇	P ₈	P ₉	P ₁₀		
Sowing dates												
D ₁ -SMW25	916.9	3968.1	0	4.6	361.9	514.2	644.5	1072.1	1544.9	2021.1	11048.3	1104.83
D ₂ -SMW26	433.6	2667.6	319.3	453.7	795.5	706.3	815.7	691.2	1706.6	2714.1	11303.6	1130.36
D ₃ -SMW27	532.9	612.7	453.7	574	179.6	674.2	410.2	512.9	2110.3	2964.4	9024.9	902.49
Mean	627.8	2416.13	257.66	344.1	445.66	631.56	623.46	758.73	1787.26	2566.53	10458.93	1045.89

Table 4: Phenophase wise PTU required for different sowing dates of soybean

Treatment	Phenophases of soybean										Total	Mean
	P ₁	P ₂	P ₃	P ₄	P ₅	P ₆	P ₇	P ₈	P ₉	P ₁₀		
Sowing dates												
D ₁ -SMW25	1138.2	5752.8	1108.2	765	1421.4	1224	1286.4	1823.4	2511	2416.2	19446.6	1944.66
D ₂ -SMW26	1096.8	5608.2	1408.8	1024.2	1500	1414.2	1153.2	1353.6	1981.2	3616.8	20157	2015.7
D ₃ -SMW27	1050	5034.6	1024.2	662.4	837.6	1029.6	778.2	1494	2402.2	3813	18125.8	1812.58
Mean	1095	5465.2	1180.4	817.2	1253	1222.6	1072.6	1557	2298.13	3282	19243.13	1924.31

P₁-Sowing to emergenceP₂-Emergence to seedlingP₃-Seedling to branchingP₄-Branching to floweringP₅-Flowering to pod formationP₆-Pod formation to grain formationP₇-Grain formation full to pod developmentP₈-pod development to pod containing full size grainP₉-pod containing full size grain to dough stageP₁₀-Dough stage to maturity**Table 5:** Seed, straw and biological yields (kg ha⁻¹) and harvest index (%) of soybean as influenced by different sowing dates and varieties of soybean

Treatment	Seed Yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest Index (%)
Sowing dates				
D ₁ -SMW25	2280.00	2869.00	5149.03	44.23
D ₂ -SMW26	2446.66	3007.50	5454.16	44.78
D ₃ -SMW27	2095.83	2566.66	4662.50	44.84
S.Em.±	62.32	64.08	78.30	--
C.D. at 5 %	244.67	251.43	307.42	--
Varieties				
V ₁ -JS 93-05	1904.44	2611.11	4515.55	42.13
V ₂ -MAUS 612	2490.66	3010.93	5501.59	45.28
V ₃ -MAUS 725	2263.77	2644.44	4908.22	46.16
V ₄ -MAUS 731	2437.77	2991.11	5428.88	44.90
S.Em.±	61.42	70.48	144.20	--
C.D. at 5 %	182.51	209.43	428.46	--
Interaction(D x V)				
S.Em.±	106.39	122.08	249.76	--
C.D. at 5 %	NS	NS	NS	--
C.V. (%)	8.10	7.51	8.50	--
G.M	2274.16	2814.39	5088.56	44.62

Conclusion

The optimal accumulation of growing degree days (GDD), helio-thermal units (HTU), and photo-thermal units (PTU) for the soybean crop was observed in the D₂ (SMW 26), with values of 2569.6 °C days, 11303.6 °C day hours, and 20157.0 °C day hours, respectively and the lowest values for GDD (2299.2 °C days), HTU (9024.9 °C day hours), and PTU (18125.8 °C day hours) were recorded during the sowing date D₃ (SMW 27).

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