

Thermal and radiation environments for assessing crop-weather relationship of soybean in eastern Madhya Pradesh

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ABSTRACT

A field experiment was conducted during with three sowing dates (23 June, 8 July and 23 July) with three varieties (JS 20-29, JS 20-34 and JS 97-52) *kharif* season of 2016 and 2017 at Jabalpur in eastern Madhya Pradesh for assessing crop weather relationship in soybean through thermal and radiation environments. The results revealed that early sown crop attained more accumulated heat units, and yield decreased with delay in sowing. The maximum and minimum temperatures during reproductive stage were positively correlated with seed yield while negatively associated with vegetative and pod development stages. Photosynthetic active radiation absorption (APAR) was maximum in June sowing in semi-determinate JS 97-52 variety at pod formation stage. Maximum leaf area index (LAI) exhibited in June sown for JS 97-52 variety during pod formation stage. Seed yield increase with increased in APAR and LAI during pod formation stage. Season length difference between normal and actual crop maturity period increased with the decrease in GDD thereby suggesting a decline in yield due to shortening of crop growing period.

Keywords: Weather parameters, soybean, GDD, APAR, LAI, season length, correlation, regression.

Soybean (*Glycine max* (L.) Merrill) ranks first among the oilseeds in the world and has a prominent place in India. Area under its cultivation was nearly 101 lakh ha in 2016-17 with production and productivity of 84 lakh MT and 822 kg ha⁻¹ (SOPA, 2018). Madhya Pradesh occupies an area and production of 49 and 50.3 per cent of a total national average. Weather variables like temperature, sunshine hours, radiation, etc has its requirement to attain optimum yield, and these requirements may vary from variety to variety within a species (Sattar *et al.*, 2017). A variation in photoperiod and temperature influenced growth and development stages, and partitioning of dry matter in this crop (Lawn 1989). With the help of crop-weather relationship studies, it is possible to judge the influence of weather parameters on growth and seed yield. Jeyaraman *et al.* (1990) stated that the production potential of soybean can be enhanced with maximum temperature of $31.2 \pm 31.6^\circ\text{C}$ and minimum temperature of $20.4 \pm 20.9^\circ\text{C}$. Similarly, crop growth is also determined by solar radiation intercepted by the canopy with the genetic characteristics (van Ittersum and Rabbinge, 1997). The reduction in photosynthetic active radiation (PAR) hampers the yield of photo-sensitive crops like soybean (Bhagat *et al.*, 2017), hence its effect on soybean in subtropical environment needs to be studied.

Additionally, ecophysiological factors like leaf area index (LAI) are a potential factor in defining yield in the subtropics where varieties are sown in a broad range of maturity groups. LAI is a useful indicator of foliage development, and influenced by both abiotic and biotic factors; thus, achievement of optimum LAI favors in reducing yield gaps in soybean production (Tagliapietra *et al.*, 2018). Therefore, it is useful to identify parameters affecting growth and seed yield at different phenophase; and also to assess the optimum weather conditions for maximizing its production in eastern Madhya Pradesh.

MATERIALS AND METHODS

A field experiment was conducted during *kharif* season of 2016 and 2017 at research farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (Latitude: 23° 09 N, Longitude: 79°53 E, Altitude: 411 m) of eastern Madhya Pradesh. The soil is clay in texture and vertisol in order. The average annual rainfall is 1358 mm of which 90 per cent rainfall is received during *kharif* season. The experiment was laid in a split plot design having three staggered dates of sowing (23 June, 8 July, 23 July) with three varieties *viz.*, JS 20-29 (semi-determinate medium maturing in 95 days), JS 20-34 (determinate extra early maturing in 85-87 days), JS

97-52 (semi-determinate late maturing in 98-102 days). These varieties were resistant to major pests and diseases in soybean. They were sown under rainfed conditions on broad bed furrow system, and adequate plant protection measures were adopted. The distance between two bed-centre was 75 cm while width of single bed as 50 cm with a row distance within bed was 45 cm. The crop was uniformly fertilized with 20kg of N, 60kg of P₂O₅ and 30kg of K₂O per hectare, and seeds were inoculated with *Rhizobium leguminosorum*, and treated with Thiometoxam 30 FS (10 g kg⁻¹ seed) prior to sowing, respectively. Standard agronomic practices for weed and insect control were practiced uniformly to maintain plots free from biotic stress. The occurrence of phenological events like emergence, branching, flowering and maturity were recorded from each plot and average dates of these phases were calculated and used for analysis. The daily weather data of the growing season were collected from nearby agromet observatory located at Jabalpur. The accumulated Growing-Degree-Day (GDD) or heat unit was worked out for different phases of growth using the following equation (Nuttonson 1995)

$$GDD = \sum [(T_{\max} + T_{\min}) / 2] - T_b$$

Where T_{max} is the maximum temperature of the day in °C

T_{min} is the minimum temperature of the day in °C

T_b is base temperature in °C as 10 °C

The correlation coefficient was worked out between soybean yield and weather parameters at different phenophases of the crop. The best fit regression equation between soybean yield and both the temperatures at different phases of growth were developed to examine the soybean-weather relationship.

The absorbed photosynthetic active radiation (APAR) was measured using line quantum sensor (LI-191 SB, LICOR Inc., NE, USA) at flower initiation, pod formation and physiological maturity stages two times in a plot utilizing four components as.

$$APAR = (PAR + RPAR) - (TPAR + RPAR)$$

The portion of the incident photosynthetic active radiation (PAR), which transmit through the plant canopy to the soil surface (TPAR) will have a portion reflected by the soil (RPAR) back into the plant canopy. Similarly, leaf area was measured at flower initiation and pod formation stages using leaf area meter (CI-202, CID Bio-Sci., WA, USA) of flat leaves of three plants per plot. Later, it was averaged as one and multiplied with the number of plants covering a ground

area of a sq. metre to analyze leaf area index (LAI).

The relation between GDD and difference in season length (days) was derived between normal length (period average of 10 years from sowing to maturity) and actual crop growing period of 2016 and 2017 years.

RESULTS AND DISCUSSION

Phenophase duration and accumulated heat unit requirement

The duration of phenological stages and heat unit required are based on two-year observations are presented in the Tables 1. There was a variation under different micro-environmental conditions at different phenophase (Table 1). The results indicated that more duration is needed of either vegetative (emergence to flower initiation), flowering (flower initiation to pod initiation) and pod development (pod initiation and maturity) stages in the first date (which may be considered as a normal sowing window) while the remaining sowing windows represent late sowing of the crop. The crop sown on 23 July require one day less to attain flowering stage than that sown on 23 June. Similar trend was revealed at pod development stage. The crop sown at normal time attain maturity in 90 days, while crop sown late reached maturity in 84 and 79 days, respectively. Being thermo-sensitive and short day plant, sowing time affect phenology of the crop from adoption to the time of maturity (Kumar and Badiyala, 2005). Variation in phenophase duration caused by changes of sowing dates, which led to early or delayed fulfillment of thermal requirements to attain a particular phenological stages (Sattar *et al.*, 2017).

Accumulated GDD was computed at different phenophase of crop growth stages (Table 1). The normal sown crop accumulated maximum GDD to reach various phenophases (1521 °C day) followed by 23 July sowing (1419 °C day). Crop sown on 8 July availed less GDD among all the phenophase than crop sown on 23 July. Shankar *et al.*, (1996) revealed that GDD requirements were more under early sown soybean. Among soybean varieties, JS 97-52 attain more GDD (1629 °C day) followed by JS 20-29 (1395 °C day) and JS 20-34 (1283 °C day) to reach maturity. Soybean cv. JS 97-52 as a long- duration variety, and needs more time to mature, it requires more heat units for completing life cycle. Similarly, June sown crop availed more time of hot summer months than July sown crop, and hence accumulate more thermal time, as also suggested by Singh *et al.* (2007) in soybean.

Table 1: Phenophase duration and accumulated growing degree-day requirements of soybean varieties at different sowing dates

Variables	Emergence		Branching		Flowering		Pod initiation		Physiological maturity	
	Days taken	GDD	Days taken	GDD	Days taken	GDD	Days taken	GDD	Days taken	GDD
Date of sowing										
23 June	6	125	26	465	41	666	55	944	90	1521
08 July	5	98	20	361	37	654	50	876	84	1467
23 July	5	90	22	339	39	629	50,	843	79	1419
Variety										
JS 20-29	6	110	23	394	40	680	52	882	82	1395
JS 20-34	6	110	22	371	33	555	43	725	75	1283
JS 97-52	5	66	23	400	45	764	60	1025	95	1629

Table 2: Correlation coefficients of weather parameters with seed yield at different phenophases in soybean

Weather Parameter	Emergence	Flower initiation	Pod initiation	Physiological maturity
Maximum temperature	-0.501*	0.631*	-0.719*	-0.139
Minimum temperature	-0.599*	0.572*	-0.932	0.033
Sunshine hours	-0.272	0.834	-0.235	0.128

* Significance at 5 % level

Seed yield- temperature relationship

A correlation analysis between weather parameters and seed yield exhibit a significant negative correlation of minimum temperature and seed yield at emergence, however both the temperatures indicates a significant positive correlation exhibit during flower initiation stage (Table 2). Except at flower initiation, maximum temperature exhibit negative correlation with seed yield. The bright sunshine hours reveals a positive correlation with seed yield during flower initiation and maturity stage. An increase in both the temperatures and sunshine hours during flower initiation may improve seed yield, while increase of these weather parameters during pod initiation may hamper seed yield. Identification of critical weather variables and their quantification at different phenophases is essential for successful crop production (Sattar *et al.*, 2017). Additionally, rainfall also plays a major role in seed yield, as water stress condition during flower and pod growth stages combined with significantly higher heat units considerably slowed down the potential reproductive growth leading to poor biomass production and low seed yield (Lal *et al.*; 1999).

A linear relationship between seed yield and temperature were obtained in the present study. Maximum and minimum temperatures were used in equation as they

showed a significant relationship with seed yield at different phenophase of crop growth. The equations at different phenological growth stages as:

(a) Sowing to emergence:

$$Y = 193 T_{\min} - 3181.5; R^2 = 0.65; n = 16; P = 0.001$$

(b) Emergence to flowering:

$$(i). Y = 1351.8 T_{\min} - 30574; R^2 = 0.56; n = 16; P = 0.004$$

$$(ii). Y = 532.8 T_{\max} - 14577; R^2 = 0.41; n = 16; P = 0.03$$

(c) Flowering to pod initiation:

$$Y = 75.3 T_{\max} - 824.7; R^2 = 0.53; n = 16; P = 0.006$$

Variation of seed yield using different regression equations exhibited that about 65 and 56 per cent variation in seed yield can be explained by minimum temperature (T_{\min}) from sowing to flowering stages. Similarly, variation in seed yield by 41 and 53 per cent can be explained by maximum temperature (T_{\max}) from emergence to flowering, and flowering to pod initiation stages.

APAR - seed yield relationship

The variation in APAR at different phenological stages among sowing dates of soybean varieties is presented in Table 3. Maximum PAR absorption exhibited at pod initiation during both the years. Among sowing dates, PAR absorbed maximum during June sowing, except at flower initiation

Table 3: Absorbed PAR (APAR) at different phenological stages of soybean varieties at different sown dates

Treatments	APAR (MJ m ⁻²) in 2016			APAR (MJ m ⁻²) in 2017		
	Flower initiation	Pod initiation	Physiological maturity	Flower initiation	Pod initiation	Physiological maturity
Dates of sowing						
23 June	279.7	466.9	312.0	399.8	537	263.6
08 July	327.5	433.7	291.5	421.1	535	370.9
23 July	214.8	267.7	286.6	219.5	258.4	277.4
Varieties						
JS 20-29	385.5	438.6	380.7	321.8	444.9	369.3
JS 20-34	216.6	364.1	189.6	299.5	383.3	262.0
JS 97-52	328.9	484.4	378.8	419.1	502.0	280.7

stage where 08 July exhibited higher APAR than sown during June. Among the varieties, absorption of PAR increases from flower initiation and reaches maximum during pod initiation stage. After then, it decline at physiological maturity stage (Table 3). Both JS 20-29 and JS 97-52 varieties are semi-determinate genotype that absorbs more PAR than determinate JS 20-34 variety. Soybean is a photosensitive crop and needs a specific PAR range (800-1200 PAR $\mu\text{mol}^{-1} \text{m}^{-2} \text{s}^{-1}$) for photosynthesis beyond which its production is affected drastically (Bhagat *et al.*, 2017).

A linear relationship between seed yield and APAR at pod formation stage is presented in the Fig. 1. The result at flower initiation was not significant ($R^2 = 0.077$) hence not considered. At pod formation stage, a positive relationship suggest an increase in seed yield with an increase in absorption of PAR. A 72 per cent variation in seed yield through PAR exhibited in soybean. A determinate genotype exhibited fewer light saturation point and photosynthetic rate than semi-determinate genotype (Bhagat *et al.*, 2017). As this rate is directly proportional to yield, hence semi-determinate genotypes will perform better under future PAR scenario of more concentration of aerosols with increase in the number of cloudy days.

LAI - Seed yield relationship

A variation in LAI during flower and pod initiation stages is presented in Table 4. LAI was not observed during physiological maturity stage as leaves were dry and desiccated. Among sowing dates, maximum LAI exhibited during June sowing followed by 08 July and 23 July sown dates. Among phenological stages, pod initiation exhibited 62-70 per cent more LAI than at flower initiation stages. Among the varieties, JS 97-52 exhibited higher LAI at both the phenological stages followed by JS 20-29 and JS 20-34

Table 4: Leaf area index of soybean varieties influenced by sowing dates at different time intervals

Treatments	LAI (2016)		LAI (2017)	
	Flower initiation	Pod initiation	Flower initiation	Pod initiation
Dates of sowing				
23 June	1.48	5.18	1.44	4.55
08 July	1.40	4.08	1.42	3.98
23 July	1.35	3.60	1.35	3.31
Varieties				
JS 20-29	1.42	4.34	1.41	4.07
JS 20-34	1.34	3.80	1.31	3.65
JS 97-52	1.49	4.74	1.49	4.13

varieties. Both semideterminate varieties achieved more LAI than a determinate JS 20-34 variety. Varieties with long maturity period achieved more LAI than short maturity period. Similarly, LAI decrease with delay in the sowing dates, regardless of maturity period and growth habit (Tagliapietra *et al.*, 2018). The pod formation period coincide with maximum LAI, as redistribution of nutrients, and other compounds from senescent leaves, branches and stem to the grains (Mundstock and Thomas, 2005). Additionally at pod filling period, higher LAI ensures maximum interception of solar radiation for grain formation.

A linear relationship between seed yield and LAI at pod formation stage is presented in the Fig. 2. The results at flower initiation stage is not significant ($R^2 = 0.39$) hence not considered. At pod formation stage, a positive relationship exist between LAI and seed yield with 82 per cent variation in seed yield due to LAI at this stage in soybean.

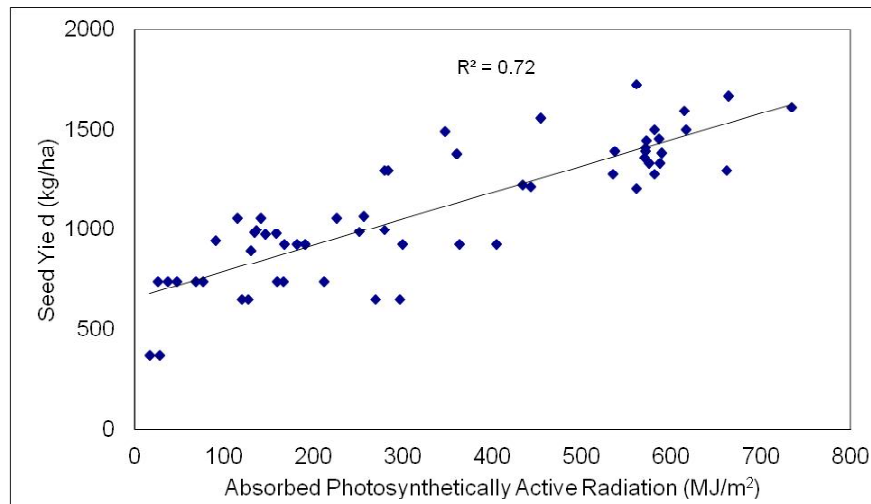


Fig. 1: Association between seed yield and photosynthetic active radiation (APAR) in soybean during pod formation stage in kharif 2016 and 2017 seasons

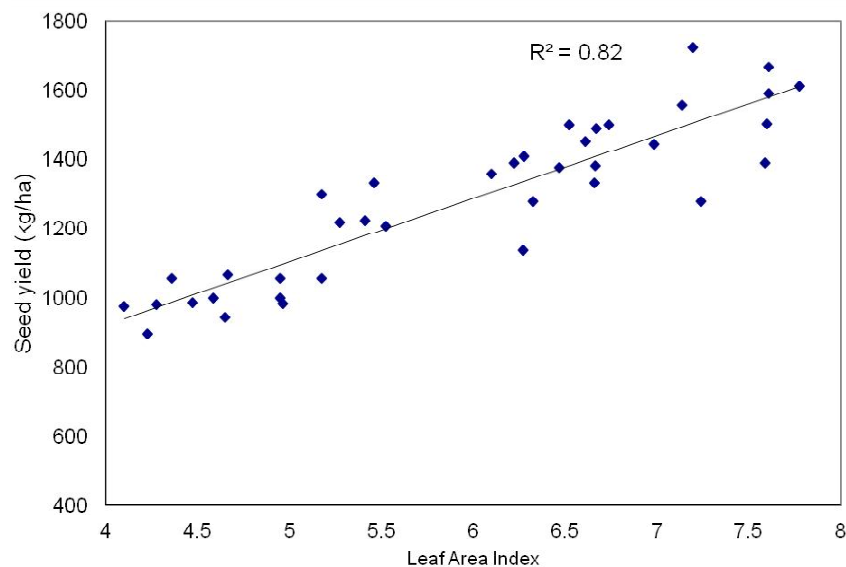


Fig. 2: Association between seed yield and leaf area index at pod formation stage in soybean

GDD-Season length relationship

A simple plot to illustrate a relationship between accumulated GDD and difference in season length is presented in Fig. 3. The effect of temperature on maturity was assessed using regression analysis. It observed increase in GDD if difference between actual and normal crop growing period is less. On the contrary, GDD will get skewed with the increase in difference of crop growing period. A day length in crop growing period influences the rate of development. A delay in sowing shortens crop maturity period, and accelerate senescence causing damage to photosynthetic cells that reduce photosynthetic rate thereby affecting crop

productivity (Al-Khatib and Pavlsen 1999).

Seed yield among sowing dates and varieties

Seed yield under different thermal environments and varieties is presented in Fig. 4. During the year 2016, maximum seed yield was observed on 23 June (1289 kg ha⁻¹) followed by 8 July (1111 kg ha⁻¹) however it reduced in 23 July (542 kg ha⁻¹) sown crop. The trend was similar in 2017 year. Among the varieties, JS 97-52 exhibited maximum seed yield (1035 and 1325 kg ha⁻¹) followed by JS 20-29 and JS 20-34 varieties in both the years. Bhatia *et al.* (2008) observed that maximum seed yield of soybean was obtained with June 20 sowing, and marginally declined as sowing was

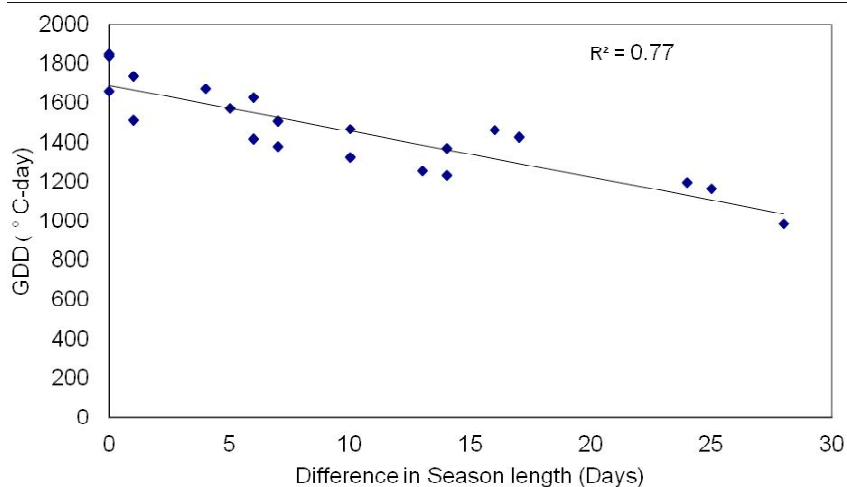


Fig. 3: Effect of growing degree day on growing length difference of soybean

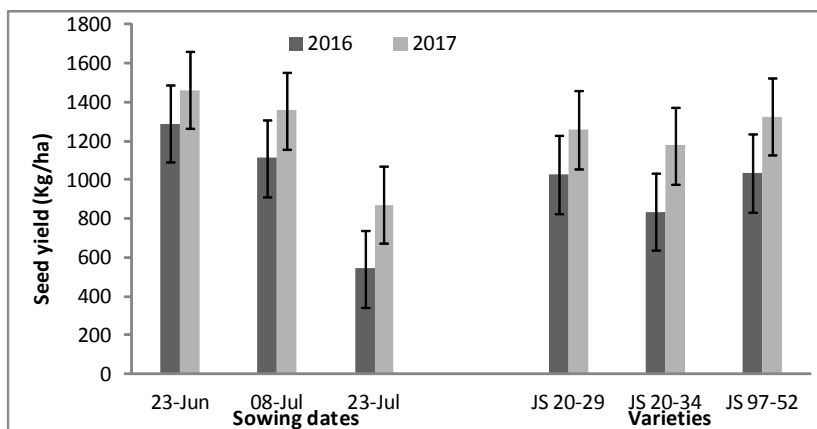


Fig. 4: Impact of date of sowing on seed yield of different soybean varieties

delayed till 10 July. Seed yield declined sharply if sown beyond 10 July. In early sowing there was a sufficient time for the variety to exploit the soil and environmental resources for their vegetative development compared to late sowing that shortens the crop duration (Shah *et al.* 1999). Additionally, more solar radiation is available for early sown crop that favors yield.

CONCLUSIONS

On the basis of two-year field experiment, it is concluded that accumulated heat units was highest under long duration semi-determinate variety in early sown (June sown) crop. Correlation analysis revealed that maximum temperature during vegetative and reproductive stage of crop growth influenced seed yield. Both the temperatures during flower initiation phase played a major role thereby affecting seed yield. High temperature during pod development stage results in lowering yield in delayed sown crop. Variation in PAR absorption was maximum during pod

initiation stage during June sowing in semi-determinate JS 97-52 and JS 20-29 varieties. Similarly, maximum LAI exhibited during pod initiation stage in June sowing for semi-determinate JS 97-52 variety. Increase in both APAR and LAI during pod formation increase seed yield of soybean. A decrease in GDD observed with an increase in season length difference between normal and actual crop maturity period. Highest seed yield was obtained when crop was sown during June, which declined sharply if sown after the first week of July in both the years.

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