

Original Research Article

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Agro-Meteorological Indices for Soybean Crop under Different Growing Environment

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ABSTRACT

Soybean, among the major crop of the region, is one of the classical short day plants and faces thermo-sensitivity in nature. The crop growing environmental conditions can be manipulated by opting different sowing dates resulting in different sets of environmental conditions for the crop, which are likely to be encountered during crop growth. An experiment was conducted during the *kharif* season of 2016-17 at the field of All India Coordinated Research Project on Agro-meteorology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (MS). Four sowing times 26th, 27th, 28th and 29th MW and three soybean genotypes JS-335, JS-9305 and TAMS-98-21 were tested in FRBD with three replications. Results revealed that, soybean sown during 26th MW recorded significantly higher seed yield with maximum heat use efficiency and water use efficiency. Soybean variety JS 335 recorded significantly higher seed yield with maximum heat use efficiency and water use efficiency. Pod formation to seed filling stage is the most important for determining the quantity of seed yield. During these stages, minimum temperature, rainfall and relative humidity (RH I & II) showed a positive and significant association with the seed yield. Increased maximum temperature and diurnal temperature range and inadequate rainfall at the growth stage of beginning seed, has the greatest impact on soybean yield. Optimum rainfall and temperatures encountered during the critical reproductive phase (PF-SF) of earlier planted soybean crop favoured higher seed yield levels.

Keywords

Growing degree days, Heat thermal unit, Photo-thermal units, Heat use efficiency, Productivity

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Introduction

Soybean (*Glycine max* (L.) Merrill.) is one of the leguminous pulse and oil seed crops in the tropical and sub-tropical regions. It is an industrial crop, cultivated for oil and protein. Despite the relatively low oil content of the seed (about 20 % on moisture free basis), soybean crop is the largest single source of edible oil and account for 59 per cent of the world's production. Other key benefit are

related to its excellent protein content of about 40 % (content all essential amino acids), high levels of essential fatty acids, numerous vitamins and minerals, isoflavones and fibre. Most of the soy products act as perfect replacements for meat and dairy products specially required for vegetarians.

In India it is largely grown in Madhya Pradesh and Maharashtra. The area covered under soybean crops in India is 108.366 lakh hectare

having production of 104.366 lakh million tonnes with productivity of 959 kg ha⁻¹. Whereas, in Maharashtra the area under cultivation is 38.008 lakh ha having production of 30.721 lakh million tonnes with productivity of 808 kg ha⁻¹. In Vidarbha, area under soybean is 19.31 lakh ha having production of 14.76 lakh millions tonnes with productivity of 776 kg ha⁻¹. In Akola, area under soybean is 2.331 lakh ha having production of 1.632 lakh million tonnes with productivity of 700 kg ha⁻¹. Madhya Pradesh is leading with 58.12 lakh ha area under soybean having production of 60.249 lakh million tonnes with productivity of 1086 Kg ha⁻¹ (www.sopa.org, 2014).

Crop growth and development are the functions of energy receipt and thermal regime in any given crop growth season. Soybean, among the major crop of the region, is one of the classical short day plants and faces thermo-sensitivity in nature. The crop growing environmental conditions can be manipulated by opting different sowing dates resulting in different sets of environmental conditions for the crop, which are likely to be encountered during crop growth. Sowing dates depict varied performance and productivity due to changed environment-plant interactions. In order to know the response of a crop to the weather it has availed during each phenophase, it is necessary to have the information justifying the responses in terms of phenotypic plasticity as well as yield of crop. With objectives quantification of crop growing environment in terms of the natural weather resource availed by the crop in different phenophase, so as to know crop response in terms of phenology, heat units availed, yield and heat use efficiency.

Materials and Methods

A field experiment was carried out at the field of All India Coordinated Research Project on

Dryland Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (MS) during *Kharif* season of 2015-16. Four sowing time 26, 27, 28 and 29 MW and three soybean genotypes JS-335, JS-9305 and TAMS-98-21 were laid out in Factorial Randomized Block Design with three replications. Soil of experimental plot was medium deep black.

Soybean genotypes were sown as per treatments. Growing degree days, helio-thermal units, photo-thermal unit, day length hours, heat use efficiency and water use indices calculated by the following formulas:

Growing degree days

Growing degree days for all treatments were calculated from daily weather data on maximum and minimum temperature as under

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

Where,

T base- base temperature as 10⁰ C

Tmax- maximum temperature

T min- minimum temperature

Heliothermal units

Heliothermal units, the product of GDD and corresponding actual sunshine hours (SS) for that day were computed on daily basis from date of sowing to particular date of phenophase and from that accumulated HTU for each phenophase and total HTU over the crop period in each treatment.

$$HTU (^{\circ}C \text{ day hour}) = \sum (GDD \times BSH)$$

Photothermal units

It is calculated by the product of GDD and corresponding day length for that day on daily basis as follows:

PTU ($^{\circ}\text{C day hr}$) = GDD x Day Length

Thermal use efficiency

Thermal use efficiency in terms of seed and biomass yield was computed treatment wise by dividing the seed yield and biomass yield of soybean by corresponding accumulated thermal units (GDD) of the treatment.

TUE = {Seed yield /Biological yield (kg ha^{-1})} / Accumulated thermal units ($^{\circ}\text{C day}$)

Crop water productivity

Crop water productivity based on actual evapotranspiration is defined as Crop yield/ Water consumptively used in ET i.e actual crop water use (Kassam and Smith, 2001) calculated as below:

CWP = Yc/Eta

Where,

CWP- Crop water productivity kg (ha-mm)^{-1}

Yc- Crop yield (kg^{-1})

Eta- Actual crop evapotranspiration (mm).

Results and Discussion

Rainfall Distribution

Rainfall distribution among various phenophase of soybean cultivars under different sowing dates is presented in Table 1. Overall, crop sown during 26 MW (28 June) received higher amount of rainfall (662.8 mm) during the total growing period, which decreased with each delayed sowing date. Rainfall across the growing period (emergence to physiological maturity) did not vary markedly in the first two sowings -D₁ (662.8 mm), D₂ (628.5 mm). Also it was more or less similar in the last two sowings D₃ (422.6 mm) and D₄ (414.4 mm). In terms of total rainfall,

during vegetative and reproductive stages : D₁, D₂, D₃ and D₄ sowing received 492.7 mm, 420.9 mm, 189.8 mm and 194.2 mm of the total amount of rainfall up to true vegetative phase. During flowering phase, the crop encountered comparatively very lesser amount of rainfall in all sowings. Besides the differential morpho-physiological response of the crop to sowing time, subdued/ sub-optimal rainfall activity and consequent suboptimal soil moisture across the pod formation to seed development phase is a common feature in the region under later sowings as compared to earlier sowing.

Deviating from the normal feature, during 2016 across the period from pod formation to full seed development rainfall was quantitatively more with later sowings. D₁, D₂, D₃ and D₄ sowings received 128.4, 146.6, 181.3 and 194.1 mm rainfall, respectively. In the present study earlier sown crop received fairly adequate amount and distribution of rainfall across the critical growing period. By and large in the later sowings, decrease amount of rainfall at the respective stages might have a progressive and cumulative inadequacy effect carried across the growing period till seed development stage.

Total rainfall received during the crop growing period and also phenophase wise the rainfall amount did not vary much among the varieties- JS-335 (526.7 mm), JS 9305 (520.8 mm) and TAMS-98-21 (548.7 mm). Slight variations observed among the rainfall amount across the phenophase of the varieties was due to differences in duration of respective variety being slightly more under TAMS-98-21 as compare to JS-9305 and JS-335.

Growing degree days (GDD)

The growing degree days were computed by considering the base temperature of 10.0 $^{\circ}\text{C}$ for soybean crop. The sum of growing degree

days ($^{\circ}\text{C}$ day) for each phenophase across the crop growing period is presented in Tables 2. The accumulated growing degree days to reach various growth stages showed variation among the dates of sowing and cultivars. The accumulated growing degree days were reasonably higher during reproductive stage (flowering to full seed development stage) as compared to vegetative stage.

Across the reproductive phenophase, seed formation to seed development phase cumulatively availed higher growing degree days (Table 2). Sowing of 26 MW accumulated highest growing degree days (1653°C day) to reach various phenophase which decreased with successive later sowings.

Singh and Arya (1994), Dhingra *et al.*, (1995) and Agarwal and Gupta (1996) reported that total dry matter yield and its portioning to different components was also drastically reduced with delay in sowing. Similar findings were also recorded by Medidia *et al.*, (2006) and Anil Kumar *et al.*, (2008), reported that GDD consumed by the crop to reach physiological maturity was higher in the first date of sown crop i.e. 30th May.

Among the cultivars the highest growing degree days were accumulated by TAMS-98-21 (1624°C day) followed by JS-335 (1568°C day) and JS-9305 (1523°C day). Accumulation of higher growing degree days was due to longer growth period in the respective sowing time and variety. During emergence all genotypes availed same number of GDD. Comparatively longer duration of each respective phenophase and total growth duration of the crop in the respective sowing time and variety cause higher rate of accumulated GDD. According to Agarwal and Gupta (1996) variety Gaurav needed more growing degree day for maturity than variety Durga.

Heliothermal units (HTU)

The heliothermal units (HTU) accumulated by the crop during different phenophase is shown in Table 2. The 14th July sown crop (D₃-28 MW) had highest accumulated HTU (7324°C day hrs) this was due to comparatively more sunshine hours across end phase of D₃ sowing.

It was followed by D₄, D₂ and D₁. This was mainly due to more number of sunshine hours available across seed formation to seed development stage in later sown crops. Dhingra *et al.*, (1995) reported that the crops sown on 5th June accumulated maximum number of heliothermal units which reduce consistently with each delay in sowing.

Among the cultivars, the highest heliothermal units (7374°C day) were observed in TAMS-98-21 followed by JS-335 and JS-9305.

Accumulation of higher HTU was primarily due to comparatively longer growth duration of crop coupled with greater sunshine hours in the respective sowing date and for the respective genotype was high accumulation of HTU. Sudha and Latha. 2016 reported that among the varieties the highest HTU required to reach maturity were noted in JS 97-52 as compared to JS-335 and JS- 9305 during both the crop season.

Photothermal units (PTU)

The accumulated PTU for attaining different phenological stages in soybean have been shown in Table 2. It was observed that different sowing time had marked influence on photo-thermal accumulation. Sowing of 26 MW (D₁) availed maximum photo-thermal units (20392°C day hr) under all the varieties and it decreased with each later sowings (D₂ to D₄). In fact earlier sown crops required more PTU to complete different phenological stages.

Table.1 Rainfall distribution (mm) among various phenophase of soybean cultivars under different sowing time

Phenophase	JS-335	JS-9305	TAMS-98-21	Mean
	D₁ - 26 MW (28.06.2016)			
Vegetative stage	495.3	487.5	495.3	492.7
Flowering	2.7	10.5	6.1	6.4
Pod formation to full seed development	141.6	103.7	140	128.4
Maturity	4.4	39.7	61.5	35.2
Total	644.0	641.4	702.9	662.8
D₂ - 27 MW (05.07.2016)				
Vegetative stage	420.9	420.9	420.9	420.9
Flowering	13.7	3.4	13.7	10.3
Pod formation to full seed development	129.7	140	170.2	146.6
Maturity	61.5	40.5	50	50.7
Total	625.8	604.8	654.8	628.5
D₃ - 28 MW (14.07.2016)				
Vegetative stage	188.7	188.7	192.1	189.833
Flowering	15.2	13.7	16.8	15.2
Pod formation to full seed development	188.9	170.2	184.7	181.3
Maturity	29.8	50	29	36.3
Total	422.6	422.6	422.6	422.6
D₄ - 29 MW (14.07.2016)				
Vegetative stage	194.2	194.2	194.2	194.2
Flowering	6.5	6.5	7.2	6.7
Pod formation to full seed development	184.7	184.7	213	194.1
Maturity	29	29	0	19.3
Total	414.4	414.4	414.4	414.4
Mean				
Vegetative stage	324.8	322.8	325.6	324.408
Flowering	9.5	8.5	11.0	9.7
Pod formation to full seed development	161.2	149.7	177.0	162.6
Maturity	31.2	39.8	35.1	35.4
Total	526.7	520.8	548.7	532.1

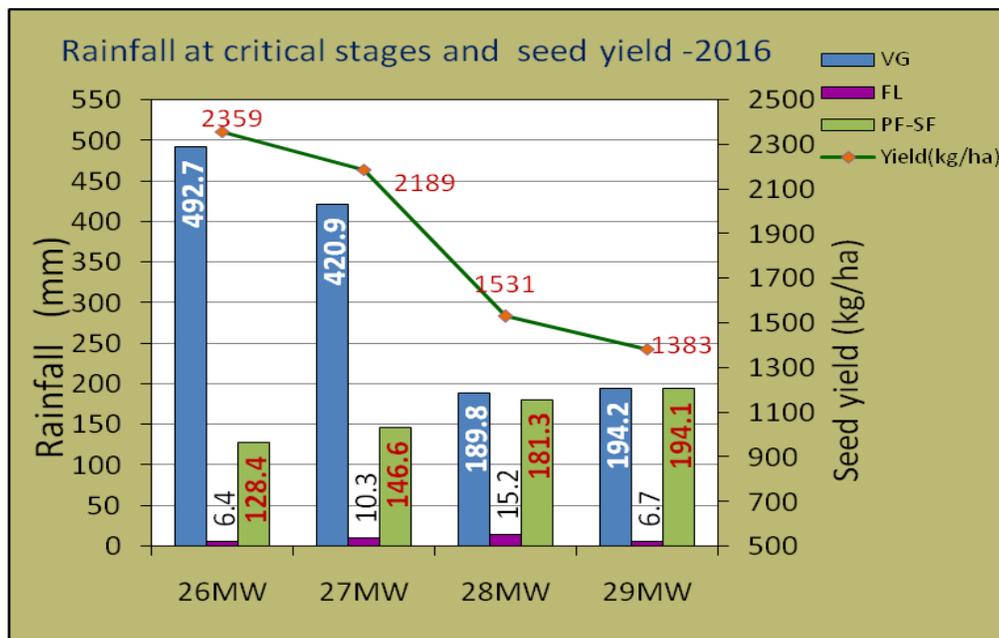
Table.2 Accumulated GDD, accumulated HTU, photo thermal units and heat use efficiency of seed and biomass of soybean varieties under different sowing time

Treatments	GDD (°C day)	Accumulated HTU (°C day hr)	Photothermal units (°C day hr)	Heat use efficiency	
				Seed	Biomass
				(Kg ha ⁻¹ °Cday ⁻¹)	
Sowing date					
D₁ - 26 MW (28 June)	1653	6610	20392	1.43	2.95
D₂ - 27 MW (05 July)	1608	6927	19657	1.37	2.82
D₃ - 28 MW (14 July)	1546	7324	18701	0.99	2.33
D₄ - 28 MW (20 July)	1478	7112	17739	0.94	2.30
Variety					
V₁ - JS-335	1568	6958	19082	1.58	2.64
V₂ - JS-9305	1523	6647	18572	1.25	2.54
V₃ - TAMS-98-21	1624	7374	19713	1.02	2.61

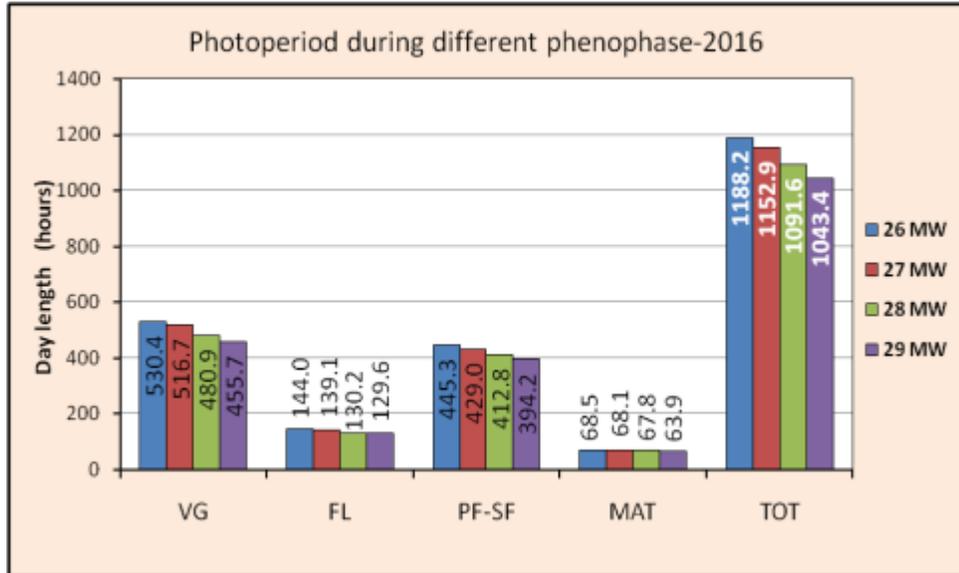
Table.3 Seed yield, total biomass yield, and water use indices of soybean varieties under different sowing time

Treatment	Seed yield (kg ha ⁻¹)	Total biomass yield (kg ha ⁻¹)	Eta (mm)	WP (kg ha-mm ⁻¹)
Sowing date				
D ₁ - 26 MW (28 June)	2359	4871	328.3	7.19
D ₂ - 27 MW (05 July)	2189	4529	307.4	7.13
D ₃ - 28 MW (14 July)	1531	3608	291.3	5.26
D ₄ - 28 MW (20 July)	1383	3397	275.1	5.03
SE(m) ±	62	121		
CD (P=0.05)	179	350		
Variety				
V ₁ - JS-335	2021	4163	300.1	6.66
V ₂ - JS-9305	1911	3876	297.9	6.34
V ₃ - TAMS-98-21	1665	4265	303.6	5.45
SE m ±	54	105		
CD (P=0.05)	155	303		
Interaction				
SE m ±	108	210		
CD (P=0.05)	NS	NS		
CV%	12	10		

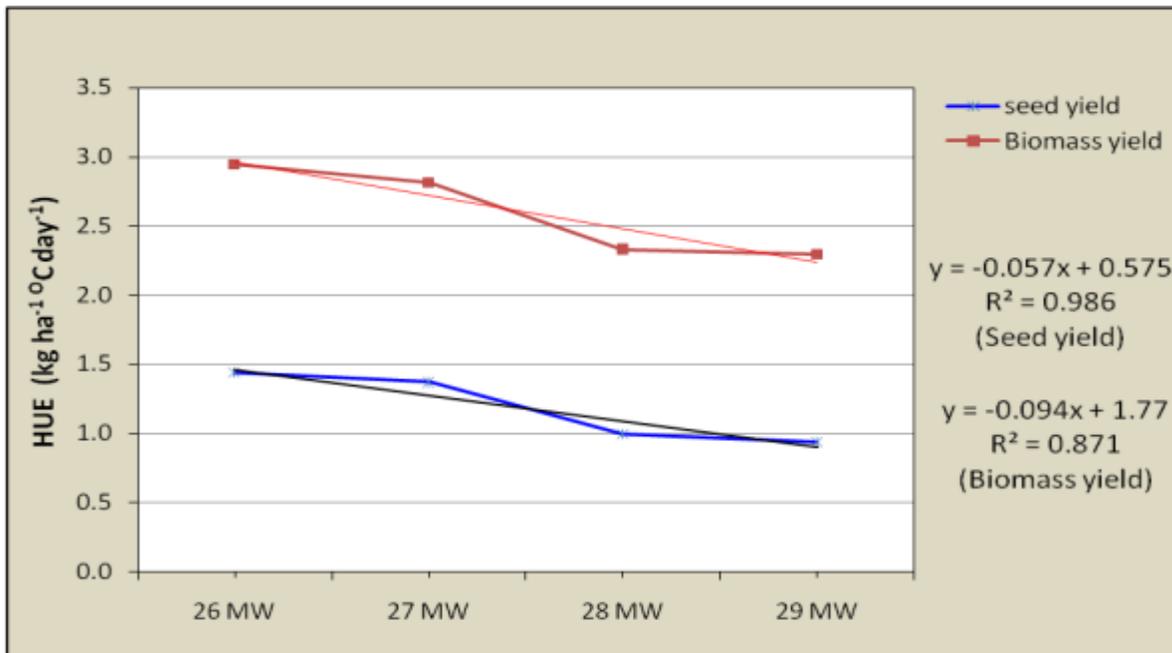
Rainfall Distribution



Day length hours



Heat use efficiency



Sudha and Latha 2016 reported that highest accumulated value of the PTU experience by the crop during sowing maturity in the early sowing (24405 and 24490 °C day) followed by second sowing (22489 and 20847°C day) and third sowing date (18634 and 18843 °C day) during both year under study.

Among the cultivars, TAMS98-21 required more PTU to complete different phenological stages and consumed the highest cumulative PTU (19713 °C day hr) followed by JS-335 (19082 °C day hr) and JS-9305 (18572 °C day hr). Accumulation of higher photothermal units was due to longer growth period and

photoperiod phenophase and total in earlier sowings compared to later sowings. Comparatively longer duration of each respective phenophase and total growth duration of the crop in the respective sowing time and variety caused higher accumulation of GDD and consequently higher photothermal units. The results are in confirmation with the findings of Sudha and Latha (2016) reported that as regards the three varieties viz. JS-335, JS-9305 and JS-97-52 the variety JS 93-05 accumulated lowest value of PTU whereas JS 97-52 accumulated highest PTU.

Day length hours

Day length, temperature and rainfall are the most important climatic factors to select a region for specific crop cultivation and production. Day length hours (sunrise to sunset hours) across different phenophase of soybean under different dates of sowing are indicated graphically.

Soybean crop encountered maximum day length hours for each of the phenophase under 26 MW sowing (D₁) and day length hours encountered for each phenophase decreased with later sowings (D₂ to D₄). Similarly, day length hours decreased gradually across each subsequent phenophase of soybean crop. Longer day length hours in earlier sowings caused extended duration of vegetative period as well as reproductive stages as compared to later sowings. Hence, the later sown soybeans progressed comparatively faster through the respective phenological stages and ultimately reduced the plant cycle causing the plant to yield less than its full potential. The relative length of the light and dark periods affects the production of carbohydrates by all crops. In order to cope with night time darkness, plants during the day allocate part of their photosynthates for storage, often as starch. This stored reserve is then degraded at night

to sustain metabolism and growth. Hence, darker period demands more allocation of photosynthates to sustain metabolism and growth reducing the share for growth and development. Nabi Khaliliaqdam (2014) recorded similar results and reported that the delay in sowing date, days to flowering and days to pod initiation decreased along with decrease in photoperiod.

Heat use efficiency

Heat use efficiency (Table 2) with respect to seed yield and biomass (seed + straw) production under different dates of sowing and in different varieties of soybean crop showed that heat use efficiency ($\text{kg ha}^{-1} \text{ } ^\circ\text{C day}^{-1}$) in terms of seed yield and biomass production was higher under D₁ (26 MW) sowing followed by D₂, D₃ and D₄. The least heat use efficiency was under 29th MW sowing (D₄). Balkrishnan and Natrajaratnam (1986) and Mahajan *et al.*, (1993) revealed that heat use efficiency was higher in 21st February than in 21st September sowing. Also reported that seed yield had positive and significant association with heat units availed at flowering and harvest stage. Sudha and Latha (2016) recorded that HUE was highest for first week of sowing followed third week of July and lowest HUE was recorded under August sown crop.

Similarly, HUE with respect to seed and biomass yield was maximum in variety JS-335. It was followed by JS 9305 in terms of seed yield and TAMS 98-21 in terms of biomass yield. HUE with respect to biomass production was higher in variety TAMS 98-21. The lowest HUE ($0.88 \text{ kg ha}^{-1} \text{ } ^\circ\text{C day}^{-1}$) in terms of seed yield was under D₄ (29 MW) sowing with TAMS 9821 and for biomass yield it was lowest ($2.22 \text{ kg ha}^{-1} \text{ } ^\circ\text{C day}^{-1}$) under D₄ (29 MW) sowing with JS-9305. Hundal *et al.*, (2003) reported that cv. SL-295 recorded higher heat use efficiency for both

dry matter and seed yield than the cultivar PK-416. Sudha and Latha (2016) recorded that among the varieties highest HUE were noted in JS 97-52 followed by JS 335 and lowest HUE in JS 93-05 during both year of crop season.

Productivity

Crop sown during 26th MW (D₁ 28 June) recorded significantly higher seed and biomass (seed + straw) yield and it was followed by 27th MW (D₂ 5th July) sowing both in respect of seed yield and biomass yield, being statistically at par (Table 3). Crop sown on 20th July (29 MW) recorded the lowest seed and biomass yields. The higher yield level achieved by 26th MW (28th June) sowing was due to occurrence of adequate rainfall (moisture) across vegetative and reproductive period stress, and comparatively favourable thermal regimes and photoperiod across the vegetative and reproductive phase of the crop as compared to remaining sowings. Further delayed sowings exposed the crop to lower soil moisture regime during vegetative growth period this year, and comparatively lower photoperiod phenophase wise particularly across critical phases of pod formation and seed development. Matsul and Nishiiri (1982) reported that delay in sowing reduced dry matter per plant.

Walab *et al.*, (1984) found that soybean cv. Clark sown on April 26th gave higher yield, heavier fresh pod weight and higher number of dry seeds pod⁻¹ compared to late sowing (15th June) under Egypt conditions. Anil Kumar *et al.*, (2008) reported that early sown soybean crop (16th June) produced more drymatter and also resulted in higher seed yield and stover than late sown crop as they are availed more growing degree days. Results are in confirmatively with Mengxuan Hu and Pawel Wiatrak (2011) and Kathmale *et al.*, (2013).

Though bright sunshine hours encountered were more towards end phase in later sowings however, limited expression of inherent potential growth and development in later sowings might have limited its use efficiency. Secondly, the shortening of the duration of various growth phases in the late sown crop might be the probable reason of the reduction in total biomass production. Results are in line with the findings of Barik and Sahu (1989) and Kathmale *et al.*, (2013).

Among the varieties, JS-335 recorded significantly higher seed yield than TAMS 98-21, however it was statistically at par with JS-9305. Variety JS-9305 also recorded significantly more seed yield over TAMS 98-21. As regards biomass yield TAMS 98-21 being statistically at par with JS-335 yielded significantly higher biomass than JS-9305. Interaction effect (sowing date x varieties) was found to be non-significant in respect of seed yield and biological yield. Bhatia *et al.*, (1999) observe that seed yields decrease with delay in sowing and varieties JS-335, NRC-2 and JS-71-05 gave the highest yields. Billore *et al.*, (2000) revealed that significantly higher number of pods plant⁻¹ and significantly higher seed yield were observed with the variety Ahilya-3 compared to JS-335, JS 71-05 and PK 472.

Water use

Different water use indices across the total growing period of soybean as influenced by different treatments are indicated in Table 2. Actual water use (Eta) decreased with later sowings. Water productivity (WP), as a ratio of yield to actual crop water use was, maximum under 26 MW sowing (D₁) and decreased with later sowings. Among the varieties, TAMS-98-21 showed higher Eta followed by JS-335 and JS-9305. WP was higher with JS-335 followed by JS-9305 and TAMS-98-21.

Thus it may be concluded that, soybean sown during 26th MW recorded significantly higher seed yield with maximum heat use efficiency and water use efficiency. Soybean variety JS 335 recorded significantly higher seed yield with maximum heat use efficiency and water use efficiency. Pod formation to seed fill stage is the most important for determining the quantity of seed yield. During these stages, minimum temperature, rainfall and relative humidity (RH I & II) showed a positive and significant association with the seed yield.

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