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Effect of sowing dates and varieties on soybean performance in Vidarbha region of Maharashtra, India

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Abstract: Soybean production is widely fluctuating in response to agro-environmental conditions year to year in Vidarbha region. Weather variations are the major determinants of soybean growth and yield. It is also important to study the response of suitable soybean varieties to varying weather parameters. So a field investigation was carried out to study the crop weather relationship of soybean and to optimize the sowing date with different soybean varieties. The results revealed that soybean crop sown up to 27^{th} MW accumulated higher growing degree days (1640.5 ^{0}C day), photothermal units (20498.1 ^{0}C day hour) and recorded significantly higher seed yield (839 kg ha^{-1}) and biological yield (2773 kg ha^{-1}) with maximum heat use efficiency (0.51 kg ha^{-1}°C day^{-1}) and water productivity (2.49 kg ha-mm^{-1}). Later sowings i.e. 30^{th} MW sowing caused decreased amount of rainfall and increased maximum temperature regime across the total growing period with consequently lower seed yield (530 kg ha^{-1}), GDD (1539.2 ^{0}C day), PTU (18689.9 ^{0}C day hour), heat use efficiency (0.34kg ha^{-1} °Cday^{-1}) and water productivity (2.05kg ha-mm^{-1}). Soybean variety TAMS 98-21 recorded significantly higher seed yield (734 kg ha^{-1}) and highest biological yield (2649 kg ha^{-1}) with maximum heat use efficiency (0.44 kg ha^{-1} °C day^{-1}), GDD (1650.5 ^{0}C day) and water productivity (2.41 kg ha-mm^{-1}). Thus, the results of this study illustrated the importance of early sowing with suitable variety of soybean and indicates that sowing upto 27^{th} MW with variety TAMS 98-21 is optimum for maximizing the yield in the Akola region of Vidarbha.

Keywords: Crop weather relationship, Soybean, Sowing date, Varieties

INTRODUCTION

Soybean is classified more as an oil seed crop than as a pulse. It contains 40-42 % of proteins and 18-20 % of oil. Due to its high nutritional value there is an increasing demand of soy food e.g. soymilk, soybean sprouts, soy nuts, several types of tofu, cottage cheese and curd. Soybean has been explored worldwide in a variety of food and is also an important constituent for animal feed. Despite of its high demand, India contributes only 3 % of world soybean production whereas the USA alone has about 34 per cent of the world soybean production followed by Brazil (30 %), Argentina (18 %) and China (4 %). There are many factors limiting soybean production at farm. These factors are improper sowing time, climatic variability, low germination percentage, poor quality seed, irrigation shortage etc. Another possible reason of low production is the non-adoption of new developed varieties. The sowing of soybean varities of high yield potential at optimum sowing time is considered as a hopeful approach to increase soybean production. Generally, the sowing dates varies depending on the climatic condition of the region and the varieties to be grown. Different varieties of soybean are sensitive to change in environmental conditions where the crop is being sown. Therefore, it is also necessary to study the genotype × environment interaction to identify the varieties which are stable in different environments (Calvino *et al.,* 2003a). Sowing dates influence soybean growth stages, due to variation in photoperiod (Han *et al.,* 2006; Kumudini *et al.,* 2007), air temperature (Chen and Wiatrak, 2010), and rainfall distribution and amount during the crop cycle (Hu and Wiatrak, 2012). Meotti *et al.* (2012) observed that 77 % of soybean yield variability was associated with the climate conditions induced by the sowing dates. Sowing date is the variable with the largest effect on crop yield (Calvino *et al.,* 2003b). Environmental conditions associated with late sowing affect crop features related to the capture of radiation and portioning of crop resources as soybean is a dicotyledonous photoperiod sensitive crop (short day) and faces thermo-sensitivity in nature. These include less vegetative growth (Board *et al.,* 1992), shorter stems (Boquet, 1990); lower reproductive nodes and shortening of the reproductive phases (Kantolic and Slafer, 2001). Delayed sowing generally shifts reproductive growth into less favourable conditions with shorter days and lower radiation and temperature (Egli and Bruening, 2000). In a simulation study, Egli and Bruening (1992) found that reduced radiation and temperature accounted for most of the reduction in

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yield associated with late planting in well watered soybean crops reaching maturity in late season. Soybean crop in Vidarbha region has emerged as a predominant rainy season crop. It has shown an unparalleled growth in area and production due to its early duration, low risk nature, suitability to double cropping, distinct yield advantage, higher price and better market support. Year to year soybean production, however, is widely fluctuating in response to agro-environmental conditions. Seasonal and daily variations in weather are the major determinants of crop growth and yield. Soybean productivity mainly depends on the prevailing weather conditions encountered across the life cycle of the soybean crop. Further, the different weather parameters affect growth and development of crop differently. Environmental conditions prevailing over a particular agro-climatic zone cannot be altered; however, sowing time of a crop can be adjusted to take maximum advantage of the environmental factors to best suit various growth stages of crop. The productivity of soybean is governed by improved genotypes coupled with matching production and protection technology. Suitability of a variety to a particular agro-climate is most important factor in realizing the yield potential which is further influenced by their response to varying growing environment (Boote *et al*. 2008). Different sowing time exposes the crop to different set of environmental conditions which gets integrated in the final crop performance respective to the sowing time. Besides, it is important to study the response of suitable soybean varieties to varying weather parameters to optimize it for increased soybean productivity. Therefore, it was contemplated to have an insight on the effect of different weather parameters and thereby agro-meteorological indices for the production of soybean crop. The objective of present study was to evaluate the effect of sowing times and varieties on yield and yield components of soybean in agro-ecological conditions of Akola, MH.

MATERIALS AND METHODS

In order to evaluate the effects of sowing dates and varieties on various yield and yield attributes of soybean, a field experiment was conducted during *kharif* season of 2014 at the All India Coordinated Research Project on Agrometeorology under Dry land Agriculture Research Centre, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (latitude of $22^0$42' North, longitude of 77^0 02' East and 307.41 meter above mean sea level). The climate of Akola is semi-arid and normal (average of 30 years) mean annual precipitation is 811.9 mm received in 42.8 rainy days. The normal mean monthly maximum temperature is 42.5 ^{0}C during the hottest month (May) while the normal mean monthly minimum temperature is 10.6 ^{0}C in the coldest month (December). Relative humidity attains the maximum value (74 – 87 %) during the south west

Table 1. Effect of various sowing dates on yield and quality attributes of different soybean varieties.

Treatment	Initial plant stand 10 DAS Lakh ha^{-1}	Final plant stand At harvest Lakh ha^{-1}	Plant height (cm) 80 DAS	Leaf area plant^{-1} (cm^2) 60 DAS	Leaf area index 60 DAS	dry matter accumulation plant^{-1} (g) 80 DAS	Pods plant^{-1}	Seed weight plant^{-1} (g)	Seeds pod^{-1}	100 seed weight (g)
Sowing time										
D_1- 27 MW (07 July)	3.88	3.82	29.98	836.42	3.72	10.97	26.58	4.33	2.58	8.32
D_2- 28 MW (14 July)	3.94	3.86	28.29	783.50	3.48	10.47	25.33	4.01	2.59	8.28
D_3- 29 MW (21 July)	3.96	3.89	26.57	672.00	2.99	8.92	20.50	3.14	2.42	7.71
D_4- 30 MW (28 July)	3.91	3.86	25.70	608.17	2.70	8.10	16.80	2.40	2.41	7.75
SE(m)±	0.04	0.03	0.79	20.60	0.09	0.22	0.57	0.14	0.05	0.17
CD (P=0.05)	NS	NS	2.27	59.31	0.26	0.63	1.65	0.42	0.15	0.48
Variety										
V_1- JS-335	3.93	3.86	25.63	718.88	3.20	9.44	22.76	3.51	2.56	8.23
V_2- JS-9305	3.94	3.87	26.40	689.56	3.06	9.21	20.03	3.20	2.48	7.79
V_3- TAMS 98-21	3.91	3.84	30.87	766.63	3.41	10.19	24.13	3.71	2.46	8.01
SE(m)±	0.03	0.02	0.68	17.84	0.08	0.19	0.50	0.13	0.04	0.14
CD (P=0.05)	NS	NS	1.96	51.37	0.23	0.54	1.43	0.36	NS	NS
Interaction										
SE(m)±	0.06	0.05	1.36	35.68	0.16	0.38	0.99	0.25	0.09	0.29
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
GM	3.92	3.86	27.63	725.02	3.22	9.62	22.30	3.47	2.50	8.01

Table 2. Effect of various sowing dates on yield and quality attributes of different soybean varieties.

Treatment	Seed yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)	Total growing period	Total Rainfall (mm)	Air Temperature (^{0}C)		Relative humidity (%)		Growing degree days (^{0}C day)
Sowing time						**Mx**	**Mn**	**RH-I**	**RH-II**	
D_1- 27 MW (07 July)	839	2773	30.26	93.3	538.7	32.8	22.9	85	54	1640.5
D_2- 28 MW (14 July)	763	2602	29.37	92.0	492.6	32.7	22.5	85	55	1608.2
D_3- 29 MW (21 July)	650	2345	27.74	90.0	453.6	32.4	22.2	83	53	1578.0
D_4- 30 MW (28 July)	530	2073	25.64	87.3	265.7	33.0	22.2	82	49	1539.2
SE(m)±	21	107	--							
CD (P=0.05)	60	309	--							
Variety										
V_1- JS-335	700	2370	29.41	90.0	437.7	32.7	22.5	84	53	1577.7
V_2- JS-9305	653	2325	27.91	88.0	437.7	32.6	22.5	84	54	1546.2
V_3- TAMS 98-21	734	2649	27.44	94.0	437.7	32.8	22.4	83	52	1650.5
SE(m)±	18	93	--							
CD (P=0.05)	52	268	--							
Interaction										
SE(m)±	36	186	--							
CD (P=0.05)	NS	NS	--							
CV %	10.4	15.2								
GM	**696**	**2448**	**28.25**	90.7	**437.7**	**32.7**	**22.4**	**84**	**53**	**1591.5**

Table 3. Effect of various sowing dates on yield and quality attributes of different soybean varieties.

Treatment	Heliothermal units (^{0}C day hr)	Photothermal units (^{0}C day hr)	Thermal use efficiency (kg ha^{-1} °Cday^{1})		Crop water use Eta (mm)	WP (kg ha-mm^{-1})
Sowing time			**Seed yield**	**Biomass**		
D_1- 27 MW (07 July)	7351.3	20498.1	0.51	1.69	336.7	2.49
D_2- 28 MW (14 July)	7599.6	19887.2	0.47	1.61	318.9	2.39
D_3- 29 MW (21 July)	7918.1	19322.0	0.41	1.49	296.5	2.19
D_4- 30 MW (28 July)	8242.3	18689.9	0.34	1.35	259.1	2.05
SE(m)±						
CD (P=0.05)						
Variety						
V_1- JS-335	7699.5	19442.5	0.44	1.50	303.2	2.31
V_2- JS-9305	7501.0	19082.3	0.42	1.50	300.1	2.18
V_3- TAMS 98-21	8133.0	20273.2	0.44	1.60	305.1	2.41
SE(m)±						
CD (P=0.05)						
Interaction						
SE(m)±						
CD (P=0.05)						
CV %						
GM	**7777.8**	**19599.3**			**303.2**	**2.31**

monsoon season and the minimum (30-40 %) during summer months. During the *kharif* season of 2014, the total rainfall received (23rd MW to 52nd MW) at Akola centre was 588.6 mm in 31 rainy days as against normal rainfall of 766.1 mm in 38.4 rainy days (1971-2000). Rainfall received during 23-52 MW was 23.17per cent in deficit (177.5 mm) than normal. The soil is clayey in texture and moderately alkaline in reaction. Proportion of sand, silt and clay was 4.80, 31.70 and 63.50 %. Soil pH and EC was 8 and 0.31 dSm-1, respectively. The organic carbon, total nitrogen, available phosphorus and potassium were 0.68 %, 0.06 %, 21.8 kg ha^{-1} and 354.9 kg ha^{-1} respectively. The cation exchange capacity was 56.4 Cmol/kg. Four sowing times (27 MW-July 07, 28 MW-July 14, 29 MW- July 21 and 30 MW- July 28) to create different set of environmental conditions for weather variability and three varieties (JS-335, JS-9305 and TAMS 98-21) were laid out in Factorial Randomized Block Design with four replications. Thus, total no. of treatments and plots were 12 and 48 respectively. Gross and net plot size was 4.5 m x 5.0 m and 3.6 m x 4.6 m respectively. The spacing was 45 cm x 05 cm. Crop management factors like land preparation, fertilizer, weed control and other cultural practices were followed as recommended for local area. All the plant protection measures were adopted to make the crop free from insects and diseases. The data were recorded on ten randomly selected plants of each entry of each replication related to growth, phenological, yield, moisture use and agro-meteorological studies. The experimental data collected during the course of investigation were statistically analyzed with factorial randomized block design programme on computer by adopting standard statistical techniques of analysis of variance (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Plant stand: The data revealed that different sowing dates and varieties had no effect on initial and final plant stand and plant population was not a variable factor due to favourable weather condition during complete july month (from 27th MW to 30th MW) which resulted into uniform emergence and its persistence throughout the crop growth period.

Plant height: The maximum plant height was recorded with D_1-27 MW (7th July) sowing whereas D_4-30 MW (28th July) produced least plant height at all stages of crop growth. Karad (1999), Kausale (2000) and Batwal *et al.* (2004) also reported that as the sowing was delayed there was reduction in plant height. The reason for increased plant height in early sowing may be the enhanced vegetative development of crop due to the favourable weather condition, particularly favourable rainfall and hence soil moisture regime throughout the growing period that facilitated better shoot growth. TAMS 98-21 (V_3) recorded significantly higher plant height at 80 days stage as compared to JS-9305(V_2) and JS-335 (V_1). The superior performance of TAMS 98-21 compared to other two varieties in terms of plant height could be mainly due to inherent genetic characteristic of the variety with better growth and extending capacity of the shoot; and may be vegetative growth getting comparatively more share of photosynthates relative to the magnitude of reproductive growth and development.

Leaf area per plant: Leaf area recorded $plant^{-1}$ showed that sowing time D_1 (7th July) produced significantly higher leaf area over the rest, except that it was at par with D_2 (14 July) at 60 days stage of crop growth. This was due to better growth and regeneration capacity of plants under favourable weather and soil moisture regime prevailed across earlier sown growing period and a sort of inadequate situation in terms of soil moisture and weather regime in late sown crop. Arora (1981) found the same and reported that in soybean number of leaves per plant were reduced with delay in sowing. In case of varieties, TAMS 98-21 produced significantly higher leaf area than JS- 9305 and it was at par with JS-335.

Leaf area index: Treatment D_1 (7 July), being at par with D_2 (14 July) at 60 days stage of crop growth, produced significantly higher leaf area index than D_3 (21 July) and D_4 (28 July). In early sown crop greater leaf area caused higher leaf area index, which decreased in later sowings as a consequence of reduced leaf area. The findings are in agreement with Singh *et al.* (1987), Jasani *et al.* (1993) and Rajendra Prasad (2002). Singh *et al.* (1987) stated that early sown soybean crop (June 15) exhibited extended vegetative and reproductive phases that exerted favorable effect on LAI compared to late sown crop (June 30 and July 15).whereas Jasani *et al.* (1993) found that the leaf area index was highest under early sowing (23rd June, 8th July) with the onset of monsoon due to favourable environment for the crop during vegetative phase. According to Rajendra Prasad (2002) early planting gives great canopy to produce maximum yield. V_3-TAMS 98-21 produced significantly higher leaf area index than V_2- JS-9305.V_3- TAMS 98-21 was at par with V_1- JS-335 at 60 DAS.

Dry matter weight per plant: Dry matter weight $plant^{-1}$ showed decreasing trend with later sowings (D_1 to D_4).The observed trend could be attributed to comparatively less favourable weather conditions and soil moisture regime encountered along the growing period by later sown crop that decreased the dry matter accumulation. Besides, growth period of the crop also decreased with each successive delay in sowing which also caused reduced dry matter accumulation in late sowings. This corroborates the findings of Matsul, S. and K. Nishiiri (1982), Park *et al*. (2000) and Anil Kumar *et al.* (2008). Matsul,S. and K. Nishiiri (1982) in their field trials on three soybean cultivars sown at 10 days intervals from 20th May to 19th July observed that delay in sowing reduced dry matter per plant. Park *et al*. (2000) reported that growth period from sowing to physiological maturity was shortened as sowing was delayed. Stem weight was decreased by late sowing. Anil Kumar *et al*. (2008) reported that early sown soybean crop (June 16) produced more dry matter and also resulted in higher seed yield and stover than late sown crop as they availed more growing degree days. V_3 (TAMS 98-21) produced significantly higher dry matter weight plant^{-1} than V_1 (JS-335) and V_2 (JS-9305). The differential dry matter accumulation among varieties may mainly be attributed to their genetic potential rather than the effect of external weather parameters which prevailed more or less in similar range along the growing period of varieties.

Pods per plant: Data regarding number of pods per plant revealed a decrease with delay in sowing time.Sowing of 27 MW (7 July, D_1) recorded highest number of pods plant^{-1} (26.58). The lowest number of pods plant^{-1} was recorded by D_4 (16.80). The above results are in conformity with the findings reported by Billore *et al.* (2000), and Batwal *et al.* (2004). Billore *et al.* (2000) observed that sowing on June 25th recorded significantly the highest number of pods plant^{-1} than July 5th , July 10th, July 15th and July 20th sowings .Batwal *et al.* (2004) reported that soybean crop sown during 25th and 26th meteorological weeks recorded the highest number of pods plant^{-1} higher seed yield at Pune, Maharashtra.Variety TAMS 98-21 (V_3) recorded the maximum number of pods plant^{-1} (24.13) that was significantly more over JS-9305 (V_2) and on par with JS-335 (V_1).

Seed weight per plant: Maximum seed weight plant^{-1} was recorded by 27 MW sowing-D_1 (4.33g). It was significantly superior over 29 and 30 MW sowings (D_3 and D_4) and at par with 28 MW sowing (D_2). Variety TAMS 98-21 recorded the maximum seed weight plant^{-1} (3.71g).Seeds pod^{-1}Treatment D_2 (14 July) recorded the maximum number of seeds pod^{-1} (2.59) statistically at par with D_1 (2.58). The findings are in agreement with Park *et al.* (1987). Park *et al.* (1987) reported that early sowing attributed to higher pods plant^{-1}, more seeds pod^{-1} and greater 100 seed weight. Differences in number of seeds pod^{-1} due to different varieties were statistically not significant. Numerically variety JS-335 recorded maximum number of seed pod^{-1} (2.56) followed by JS-9305 (2.48) and TAMS 98-21 (2.46).

Hundred seed weight: D_1 recorded the maximum hundred seed weight (8.32 g). JS-335 recorded maximum hundred seed weight (8.23g) followed by TAMS 98-21 (8.01 g) and JS-9305 (7.79 g) which is not significant statistically. The higher yield components with 7 July sowing (D_1-27MW) and 14th July sowing (D_2-28MW) was due to better expression of growth characters like plant height, dry matter production and leaf area due to favourable weather and soil moisture regime encountered across different phenophase by these two sowing times as compared to later sowings of D_3 (21 July) and D_4 (28 July). Later sowings had availability of progressively shorter rainy season and comparatively less favourable weather conditionsThis corroborates the findings of Park *et al.* (1987) . Park *et al.* (1987) reported that early sowing attributed to higher pods plant^{-1}, more seeds pod^{-1} and greater 100 seed weight.

Seed yield: Significantly highest seed yield (839 kg ha^{-1}) was obtained when crop was sown on 7th July (D_1). Crop sown on 28th July (D_4) recorded the lowest seed yield level of 530 kg ha^{-1}. The results are in conformity with Anil Kumar *et al*. (2008, Mengxuan Hu and Pawel Wiatrak (2011) and Kathmale *et al.* (2013). Anil Kumar *et al*. (2008) reported that early sown soybean crop (June 16) produced more dry matter and also resulted in higher seed yield and stover than late sown crop as they availed more growing degree days. Mengxuan Hu and Pawel Wiatrak (2011) reported that delayed planting date and unfavorable environmental conditions have a negative effect on soybean growth, development and so affect the the grain yield. Kathmale *et al.* (2013) reported that significantly higher soybean seed yield was noticed in first two sowing dates i.e., on 25th June and 5th July. Soybean variety TAMS 98-21 recorded significantly higher seed yield (734 kg ha^{-1}) over JS-9305 (653 kg ha^{-1}), however it was statistically at par with JS-335 (700 kg ha^{-1}). Superior yield level with TAMS 98-21 was due to better expression of reproductive components as compared to JS-335 and JS-9305.

Biological yield: Crop sown on 7thJuly (D_1) recorded significantly higher biological yield (2773 kg ha^{-1}) at par with 14th July sowing (D_2). Progressive decrease in biological yield was noticed beyond 14th July (D_2) sowing under D_3 (21st July) and D_4 (28th July). TAMS 98-21 recorded the highest biological yield (2649 kg ha^{-1}).

Harvest index: Maximum har:vest index was recorded with D_1 (07 July, 30.26%) sowing time whereas D_4 recorded the least harvest index of 25.64 %. The above results are in conformity with Billore *et al.* (2000). Billore *et al.* (2000) observed that sowing on June 25th recorded significantly the highest harvest index than July 5th , July 10th, July 15th and July 20th sowings .Among the varieties, JS-335 recorded the maximum harvest index (29.41) followed by JS-9305 (27.91 %) and TAMS 98-21 (27.44 %). The finding shows better translocation efficiency of JS-335 compared to JS-9305 and TAMS 98-21.

Total growing period: Early sowing (27th MW) required more number of days for attaining various phenological stages reaching maturity in 93.3 days. Subsequent three sowings took 92, 90 and 87.3 days for maturity. This was due to cumulatively decreased duration of phenophases in response to the weather variables in each of the successive delayed sowing. This is in conformity with Mengxuan Hu and Pawel Wiatrak (2011). Mengxuan Hu and Pawel Wiatrak (2011) reported that changes in photoperiod, temperature, and precipitation with delayed planting decrease the duration of vegetative and reproductive stages. The maturity period averaged was more in variety TAMS-98-21 (94 days) followed by JS-335 (90 days) and JS-9305 (88 days). This was more due to inherent genetic characteristics of the variety rather than any other interacting factor.

Rainfall distribution, air temperature regime and relative humidity regime: Crop sown during 27 MW (7^{th} July) received higher amount of rainfall (538.7 mm) during the total growing period, which decreased with each delayed sowing date. All three varieties received an equal amount of rainfall. The maximum and minimum temperature regime did not vary much and remained more or less similar across the total growing period and among the varietie**.** Across the total growing period, morning (85 to 82 %) and evening relative humidity (55 to 49 %) did not show marked variation across D_1 to D_4 sowing environment. Among the varieties, again morning and evening humidity regime did not show marked variation and remained more or less similar.

Growing degree day: Across the total growing period (emergence to physiological maturity) of the crop the highest heat units were accumulated by D_1 (1640.5 ^{0}Cday) closely followed by D_2 (1608.2 ^{0}C day), D_3 (1578.0 ^{0}C day) and D_4 (1539.2 ^{0}C day). TAMS 98-21 (V_3) availed more number of GDD followed by JS-335 (V_1) and JS-9305 (V_2). Medida *et al*. (2006) and Anil Kumar *et al*. (2008) reported similar findings. Medida *et al*. (2006) reported that growing degree-days consumed by the crop to reach physiological maturity was higher in first date sown crop (30 May) than other sown crops (24 June and 30 June). Anil Kumar *et al*. (2008) reported that early sown soybean crop (June 16) availed more growing degree days.

Heliothermal units: Late sown crop D_4 (30 MW) availed higher HTU (8242.3 ^{0}C day hour) followed by D_3 (7918.1^{0}C day hour), D_2 (7599.6 day hour) and D_1 (7351.3^{0}C day hour). This was mainly due to more number of sunshine hours available across seed formation to seed development stage in later sown crops (D_3 and D_4). TAMS 98-21 (V_3) accrued more number of HTUs (8133.0 ^{0}C day hour) followed by JS-335 (7699.5^{0}C day hour) and JS-9305 (7501.0^{0}C day hour).

Photothermal unit: Early sown crop D_1 (27 MW) availed higher PTU (20498.1 ^{0}C day hour) followed by D_2 (19887.2 ^{0}C day hour), D_3 (19322.0^{0}C day hour) and D_4 (18689.9 ^{0}C day hour). TAMS 98-21 (V_3) accrued more number of PTUs (20273.2 ^{0}C day hour) followed by JS-335 (19442.5 ^{0}C day hour) and JS-9305 (19082.3 ^{0}C day hour).

Thermal use efficiency: Amongst the sowing time, thermal use efficiency in terms of seed yield was found to be maximum (0.51 kg ha^{-1} °C day^{-1}) under 27 MW (07 July) sowing. Thermal use efficiency with respect to biomass production was more with 27 MW sowing (1.69 kg ha^{-1} °Cday^{-1}). Among the varieties, thermal use efficiency in terms of seed yield was similar and higher with V_1- JS-335 and V_3–TAMS 98-21 (0.44 kg ha^{-1} °C day^{-1}) followed by V_2–JS-9305 (0.42 kg ha^{-1} °C day^{-1}). Thermal use efficiency in terms of biomass yield was higher with V_3–TAMS 98-21 (1.60 kg ha^{-1} °C day^{-1}) followed similarly by JS 9305 and JS-335 (1.50 kg ha^{-1} °C day^{-1}).

Crop water use and water productivity: Under different sowing time, actual crop water use (Eta) was the maximum (336.7 mm) in D_1 followed by D_2 (318.9 mm), D_3 (296.5 mm) and D_4 (259.1 mm). Amongst the varieties, actual crop water use (Eta) was the maximum with V_3 (305.1 mm) followed by V_1 (300.1 mm) and V_2 (300.1 mm). Water productivity (WP) was maximum with D_1 (2.49 kg ha-mm^{-1}) followed by D_2 (2.39 kg ha-mm^{-1}), D_3 (2.19 kg ha-mm^{-1}) and D_4 (2.05kg ha-mm^{-1}). Amongst the varieties, TAMS-98-21 recorded the maximum WP (2.41 kg ha-mm^{-1}) followed by JS-335 (2.31 kg ha-mm^{-1}) and JS-9305 (2.18kgha-mm^{-1}).

Conclusion

The results obtained from present investigation revealed that soybean crop sown up to 27^{th} MW accumulated higher growing degree days (1640.5 ^{0}C day), photothermal units (20498.1 ^{0}C day hour) and recorded significantly higher seed yield (839 kg ha^{-1}) and biological yield (2773 kg ha^{-1}) with maximum heat use efficiency (0.51 kg ha^{-1} °C day^{-1}) and water productivity(2.49 kg ha-mm^{-1}). Soybean variety TAMS 98-21 recorded significantly higher seed yield (734 kg ha^{-1}) and highest biological yield (2649 kg ha^{-1}) with maximum heat use efficiency (0.44 kg ha^{-1} °C day^{-1}), GDD (1650.5 ^{0}C day) and water productivity (2.41 kg ha-mm^{-1}). Thus, the results of this study illustrated the importance of early sowing with suitable variety of soybean as the sowing earlier seems to present the greatest opportunity to maximize yield and yield components. So, sowing of soybean should not be delayed beyond 27^{th} MW. In conclusion, the sowing upto 27^{th} MW with variety TAMS 98-21 is optimum for maximizing the yield in the Akola region of Vidarbha.

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