The Pharma Innovation Journal 2023; 12(1): 1866-1870

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(1): 1866-1870

www.thepharmajournal.com
Received: 27-10-2022
Accepted: 01-12-2022

AR Tupe
AICRP on Agrometeorology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

DW Thawal
Department of Agrometeorology, MPKV, Rahuri, Maharashtra, India

SB Kharbade
Department of Agrometeorology, MPKV, Rahuri, Maharashtra, India

MM Ganvir
AICRP for Dryland Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

ST Morey
AICRP on Agrometeorology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

SV Lunge
AICRP on Agrometeorology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

RS Mali
AICRP for Dryland Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Corresponding Author:
AR Tupe
AICRP on Agrometeorology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Effect of sowing date on thermal time requirement, heat use efficiency and radiation interception of soybean

AR Tupe, DW Thawal, SB Kharbade, MM Ganvir, ST Morey, SV Lunge and RS Mali

Abstract
To study agrometeorological indices for soybean crop under different sowing dates, the experiment was conducted at the experiment field of Department of Agricultural Meteorology. College of Agriculture Pune-5 during *kharif* seasons of 2012-13 and 2013-14. The experiment was laid out in a Split Plot Design with four replications. The main plot was constituted of four sowing dates in the month of June and July (fortnight interval) and in sub plot factor comprised of three soybean genotypes [(JS-335, MACS-450 and DS-228 (Phule Kalyani)]. The soybean crop was sown in I FN of June (S_1) accumulated higher Growing Degree Days (GDD) and significantly higher biomass and seed yield with maximum heat use efficiency. Subsequent, sowings beyond II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4) during 2012 and 2013 encountered higher amount of heat use efficiency and rainfall during vegetative and flowering stage and decreasing trend of heat use efficiency and rainfall across the critical reproductive stage of seed formation to development which consequently resulted in lower seed yield.

Keywords: Soybean, different sowing dates, GDD, HTU, HUE

1. Introduction

Soybean (*Glycine max* (L.) Merrill) has become the miracle of twenty first century. It is paramount importance in human and animal nutrition. It is the cheapest source of high quality protein. Soybean is cheapest source of vegetable oil and protein. It contains about 40% protein well balanced in essential amino acids, 20% oil rich with poly unsaturated fatty acids specially Omega 6 and Omega 3 fatty acids, 6-7% total mineral and 5-6% crude fibre. Soybean has got medicinal value and therefore it is used in preparing antibiotics. Soybean protein is rich in the valuable amino acid lycine (5%), good amount of minerals and vitamins (thiamin and riboflavin) and its sprouting grains contain a considerable amount of Vitamin-C (Singh, 1996) [15]. In bridging the gap between requirement and availability of proteins soybean assumes a greater importance (Pawar, 2006) [10]. The low productivity of soybean both at national and state level is attributed to abiotic (moisture and temperature) and biotic stresses (insect pests and diseases).

Soybean is one of the short day plants and most of its genotypes respond as quantitative short day plant. Optimum temperature for germination of soybean is approximately 30 ^{o}C with base temperature of 10 ^{o}C (Ghadekar, 2001) [5]. The variation of photo-period sensitivity among soybean genotypes allows the crop to grow successfully across a wide range of latitudes. Photo-period influences the rate of development during pre and post-flowering stages. Changes in photo-period and temperature are reported to alter the happening of growth stages, the growth and partitioning of dry matter of this photo-period and thermo-sensitive short day C3 crop (Lawn 1989) [8].

The growth and development of soybean plants largely influenced directly or indirectly by heat unit requirement. The occurrence of different phenological events during crop growth period in relation to temperature can be estimated by using accumulated heat units or growing degree days. Knowledge of accumulated GDD (growing degree days) can provide an estimate of harvest date as well as crop development stage. That's why this study has been undertaken for this crop for estimating GDD requirements and other related indices and its production relations.

2. Materials and Methods

The present experiment was laid out in 'D' division of Agronomy Farm, at the experiment field of Department of Agricultural Meteorology. College of Agriculture Pune-5 during *kharif* seasons of 2012 and 2013. It is located on 18^o 32` N latitude and 73$^o$ 51` E longitude. The topography of the experimental field was well leveled and uniform. The soil of this plot was Vertisol (medium black) clayey in texture. The field was well drained having depth more than 90 cm. Representative samples were collected to know the chemical properties of the soil from depth 0-30 cm and 0-90 cm. The experiment soil was clayey vertisol having clay content 45.44%, pH-8.1, E.C-0.84 (d sm-1), available nitrogen 212.20 kgha-1, available P2 05 (23.86 kgha-1) and available K2 0 360.0 kg ha-1. The present experiment was laid out in split design four sowing dates (15, 30 June and 13, 30 July) and varieties (JS 335, MACS-450 and DS-228) replicated four times. The gross plot size was 4.0 x 3.6 =14.4 m^2 and net plot of size 3.0 m X 2.7 m was harvested for data collection. Seed rate of 75 kg ha-1 was used for sowing at spacing 45 cm X 5 cm in all treatments. Recommended dose of N and P_2O_5 was applied @ 50:75 kg N:P ha^{-1} through urea (46% N) and single super phosphate (16%, P_2O_5), respectively, at the time of sowing. Growing degree day was worked by using a base temperature of 10 ^{o}C. The sums of HTU for particular phenophases of interest determined by multiplying degree days with actual bright sun shine hours. Thermal use efficiency (TUE) for total dry matter was obtained as under:

$$\text{TUE (gm-}^{2/0}\text{ day)} = \frac{\text{Biomass (gm-}^{2}\text{)}}{\text{GDD (}^{0}\text{ days)}}$$

3. Results and Discussion

i) Accumulated growing degree day (GDD)

The early sown crop I FN of June (S_1) accumulated highest growing degree days (1515.1 ^{o}C day) to reach various phenophases which decreased with successive delayed sowing shown in Table 1. This was due to the availability of longer growth period for early sown crop. Amongst the varieties, in respect of GDD availed across vegetative and reproductive phases, by and large DS-228 (V_3) availed more number of GDD followed by MACS-450 (V_2), JS-335 (V_1). Comparatively longer duration of each respective phenophases and total growth duration of the crop in the respective sowing times and Varieties caused higher accumulation of GDD. Similar results were reported by Shrivastava *et al*. (2000) [14], Seddigh and Jolliff (1984) [13], Upendrashankar *et al*. (1996) [17] and Jadhao (2009) [6].

ii) Accumulated Helio-thermal units (HTU)

Helio-thermal units shown in Table 2. The heliothermal units (HTU) availed to reach various growth stages noticeably differed sowing times. Among different crop phenophases, the accumulated HTUs were higher when cumulated across reproductive stage as compared to vegetative stage. During the year 2012, Overall early sown crop I FN of June (S1) availed higher HTU (6311.2 0C day hour) followed by II FN of July (S4) (5936.2 0C day hour), II FN of June (S2) (5632.9 0C day hour) and I FN of July (S3) (5542.7 0C day hour). This was mainly due to more number of sunshine hours available across seed formation to seed development stage in middle sown crops (S2 and S3). During the year 2013, Overall, late sown crop II FN of July (S4) availed higher HTU (7165.0 0C day hour), followed by I FN of July (S3) (5554.3 0C day hour), II FN of June (S2) (4666.4 0C day hour) and I FN of June (S1) (4547.6 0C day hour). This was mainly due to more number of sunshine hours available across seed formation to seed development stage in later sown crops (S3 and S4). During both the years i.e. 2012 and 2013, amongst the varieties by and large, DS-228 (V_3) accrued more number of HTUs followed by MACS-450 (V_2), and JS-335 (V_1).

Table 1: Accumulated growing degree days (^{o}C day) across various phenophases as influenced by sowing times and varieties (2012 and 2013)

Treatment	Phenophase *															
	EM		VG		FL		PF		SF		FSD		M		Total	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
A) Sowing times																
S_1 (I FN of June)	108.5	90.9	557.2	490.2	178.1	166.7	179.8	178.2	180.3	163.1	212.4	212.0	99.0	112.6	1515.1	1439.6
S_2 (II FN of June)	104.8	90.6	484.9	481.2	179.0	179.5	165.3	176.2	168.0	152.2	189.7	188.4	123.0	104.4	1414.6	1372.7
S_3 (I FN of July)	97.4	85.0	463.2	455.9	170.7	191.5	161.8	201.5	176.1	183.1	173.9	170.1	110.9	90.8	1353.9	1377.7
S_4 (II FN of July)	99.6	96.9	469.1	461.2	158.5	190.3	163.9	164.0	176.5	170.0	117.6	187.8	107.0	96.8	1292.0	1366.7
B) Varieties																
V_1 (JS-335)	108.5	107.3	525.6	459.9	163.3	162.8	164.8	160.1	166.6	168.9	182.8	176.2	99.0	92.0	1410.4	1327.0
V_2 (MACS-450)	108.5	107.3	542.0	486.7	178.1	151.0	164.8	160.3	180.3	181.1	198.2	194.9	99.0	112.6	1470.7	1393.8
V_3 (DS-228)	108.5	107.3	557.2	473.9	178.1	178.1	179.8	177.4	180.3	194.7	212.4	227.0	99.0	112.6	1515.1	1470.7
GM	105.1	97.9	514.2	472.7	172.2	174.3	168.6	174.0	175.4	173.3	183.8	193.8	105.2	103.1	1424.5	1392.6

Table 2: Accumulated heliothermal units (^{o}C day's hrs) across various phenophases as influenced by sowing times and varieties (2012 and 2013)

Treatment	Phenophase *															
	EM		VG		FL		PF		SF		FSD		M		Total	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
A) Sowing times																
S_1 (I FN of June)	598.7	129.6	2652.5	1009.9	240.2	345.8	650.5	683.1	1016.4	627.8	701.6	1209.9	451.4	540.3	6311.2	4547.6
S_2 (II FN of June)	563.9	248.3	1239.4	789.6	822.9	783.5	816.3	722.9	605.0	858.3	724.3	838.8	861.1	425.0	5632.9	4666.4
S_3 (I FN of July)	332.2	53.6	1335.3	1132.8	875.4	814.7	453.9	1143.7	851.2	670.6	941.4	1051.6	753.3	687.4	5542.7	5554.3
S_4 (II FN of July)	118.2	281.7	2099.6	2156.2	474.6	896.3	1047.8	576.3	730.8	1196.9	998.8	1326.7	466.4	730.7	5936.2	7165.0
B) Varieties																
V_1 (JS-335)	598.7	232.6	2596.6	899.9	213.5	110.0	570.7	571.6	1006.8	878.6	633.1	949.8	451.4	364.6	6070.8	4007.2

V_2 (MACS-450)	598.7	232.6	2652.5	906.9	240.2	220.5	570.7	535.0	1016.4	799.1	694.5	1188.6	451.4	500.6	6224.4	4383.4
V_3 (DS-228)	598.7	232.6	2652.5	906.9	240.2	268.9	650.5	686.6	1016.4	800.4	701.6	1308.9	451.4	540.6	6311.2	4744.8
GM	487.0	201.6	2175.5	1114.6	443.8	491.4	680.1	702.7	891.9	833.1	770.8	1124.9	555.2	541.3	6004.2	5009.8

iii) Thermal use efficiency (TUE)

During the year 2012, initial sowing time I FN of June (S_1) upto II FN of July (S_4) decreasing trend of thermal use efficiency was found data presented in Table 3. The highest thermal use efficiency with more grain yield is observed in plant with sowing taken as I FN of June (S_1) (1.53 kg/ha/D °C), over the rest of sowing times which were followed by plant with sowing time of II FN of June (S_2) (1.48 kg/ha/D °C), I FN of July (S_3) (1.28 kg/ha/D °C) and II FN of July (S_4) (1.12 kg/ha/D °C) lowest thermal use efficiency in terms of grain yield observed in plant with sowing taken on II FN of July (S_4) (1.12 kg/ha/D °C). It is proved that there is decrease trend of thermal use efficiency with increase in sowing times. Same trends was observed in biological yield where plant with sowing as I FN of June (S_1) (3.99 kg/ha/D °C) shown highest thermal use efficiency followed by plant with sowing times of II FN of June (S_2) (3.89 kg/ha/D °C), I FN of July (S_3) (3.66 kg/ha/D °C) and II FN of July (S_4) (3.47 kg/ha/D °C). Thermal use efficiency reduces with late sowing plant and lowest thermal use efficiency observed in plant with sowing done on II FN of July (S_4) (3.47 kg/ha/D °C) for biological yield.

Similar trend was observed during the year 2013, initial sowing times I FN of June (S_1) upto II FN of July (S_4) decreasing trend of thermal use efficiency was found. The highest thermal use efficiency with more grain yield is observed in plant with sowing taken as I FN of June (S_1) (2.12 kg/ha/D°C), over the rest of sowing dates which were followed by plant with sowing time II FN of June (S_2) (2.02 kg/ha/D°C), I FN of July (S_3) (1.83 kg/ha/D °C) and II FN of July (S_4) (1.70 kg/ha/D °C) lowest thermal use efficiency in terms of grain yield observed in plant with sowing taken on II FN of July (S_4) (1.70 kg/ha/D °C). Thermal use efficiency with respect to biological yield was more with II FN of June (S_2) (3.93 kg/ha/D°C), followed by plant with sowing times of I FN of June (S_1) (3.89 kg/ha/D °C), I FN of July (S_3) (3.67 kg/ha/D °C) and II FN of July (S_4) (3.48 kg/ha/D °C). Thermal use efficiency reduces with late sowing plant and lowest thermal use efficiency observed in plant with sowing done on II FN of July (S_4) (3.48 kg/ha/D °C) for biological yield. Thermal use efficiency in terms of seed yield and biomass yield was higher with DS-228 (V_3) followed by MACS-450 (V_2) and JS-335 (V_1) during both the years 2012 and 2013.

iv) Radiation interception (RI)

During the year 2012, it was observed from the data presented in Table 4 that the highest percentage of radiation interception was recorded in the crop sown I FN of June (S_1) followed by all other sowing times in various phenological stages of soybean crop and the lowest percentage of radiation interception was recorded in the crop sown during II FN of July (S_4). It was observed that, the general mean percentage of radiation interception was found highest at vegetative stage (64.43%), it was constant at flowering pod formation stage (60.97 and 60.18%) respectively, and thereafter the per cent radiation interception declined till the harvest maturity.

During the year 2013, it was observed from the data presented in Table 5 that the highest percentage of radiation interception was recorded in the crop sown during I FN of June (S_1) followed by all other sowing times in various phenological stages of soybean crop and the lowest percentage of radiation interception was recorded in the crop sown during II FN of July (S_4). It was observed that, the general mean percentage of radiation interception was found highest at vegetative stage (76.99%), it was constant at flowering pod formation stage (66.87 and 66.82%), respectively, and thereafter the per cent radiation interception declined till the harvest maturity. Similar results were recorded by Singh and Hundal (2004) [16].

During the year 2012 and 2013, comparatively it is observed that the radiation interception was higher in the year 2013 than the year 2012. The highest percentage of radiation interception was recorded in the variety DS-228 (V_3) as compared to the varieties MACS-450 (V_2) and JS-335 (V_1) at vegetative and full seed development stage during both the years. This is attributed to higher canopy development in early sowing, as it evident from higher dry matter production in this genotype. Similar results were recorded by Board and Harvelle (1993) [3]; Jameo (1987) [7], Board *et al.* (1997) [4] and Jadhao (2009) [6].

v) Seed yield (q ha-1), biological yield (q ha-1) and harvest index

The data on seed yield (q ha-1), biological yield (q ha^{-1}) and harvest index as influenced by different treatments are presented in Table 6. Different sowing times had a profound influence on the seed yield. Significantly highest seed yield (22.87 q ha^{-1}) biological yield (59.48 q ha^{-1}) and harvest index (38.44 %**)** in 2012 were obtained when crop was sown I FN of June (S_1), but significantly superior over II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4), it was followed by II FN of June (S_2), I FN of July (S_3). Crop sown on II FN of July (S_4) recorded the lowest seed yield (15.47 q ha^{-1}), biological yield (47.86q ha^{-1}) harvest index (32.33%). Lowest grain yield, biological yield (ha^{-1}) and harvest index (%) were recorded during 2012 under II FN of July (S_4) when sowing taken on. Similar trend were observed during 2013, significantly highest seed yield (29.79 q ha^{-1}), biological yield (54.58 q ha^{-1}) and harvest index (54.58%) were obtained when crop was sown I FN of June (S_1), but significantly superior over II FN of June (S_2), I FN of July (S_3) and II FN of July (S_4), it was followed by II FN of June (S_2), I FN of July (S_3). The mean values were higher when the crop was sown on I FN of June (S_1) during both the years for all vegetative and reproductive attributes indicating that earlier sowing enabled the crop to express the inherent potential to the maximum as compared to later sowings. Other authors (Mahapatra (1998) [11], Rajendra Prasad (2002) [12], Anil kumar *et al.* (2008a) [1] have noted similar decisive effect of sowing times on soybean growth and development and reported reductions in various morpho-physiological attributes with delayed sowing due to reduced soil moisture regime increase disease incidence and less favourable weather variables. During the years 2012 and 2013, Soybean variety DS-228 (V_3) recorded significantly higher seed yield (q ha^{-1}), biological yield (q ha^{-1}) and harvest index over MACS-450 (V_2) and JS-335 (V_1). Higher grain yield in DS-228 (V_3) might be due to higher light interception also. Similar result were reported by Lingaraju *et al.* (1995)

[9], Board *et al.* (1997) [4], Bhatia *et al.* (1999) [2] and Jadhao (2009) [6].

Table 3: Thermal use efficiency in terms of seed yield and biological production (kg ha^{-1} °C day^{-1}) as influenced by sowing times and varieties (2012 and 2013)

Varieties	Sowing date									
	S_1 (I FN of June)		S_2 (II FN of June)		S_3 (I FN of July)		S_4 (II FN of July)		Mean	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
V_1 (JS-335)	1.24	2.03	1.11	1.91	1.06	1.68	0.97	1.56	1.09	1.79
	3.43	3.77	3.44	3.89	3.36	3.49	3.25	3.30	3.37	3.61
V_2 (MACS-450)	1.58	2.12	1.64	2.01	1.22	1.84	0.98	1.70	1.35	1.92
	4.13	3.89	4.17	4.03	3.73	3.71	3.35	3.60	3.85	3.81
V_3 (DS-228)	1.78	2.22	1.70	2.12	1.55	1.97	1.42	1.84	1.61	2.04
	4.40	4.01	4.07	3.86	3.87	3.80	3.80	3.55	4.03	3.81
Mean	1.53	2.12	1.48	2.02	1.28	1.83	1.12	1.70	1.35	1.92
	3.99	3.89	3.89	3.93	3.66	3.67	3.47	3.48	3.75	3.74
Bold figures indicate heat use efficiency in terms of biomass										

Table 4: Radiation interception (%) encountered during soybean phenophases under sowing times and varieties (2012)

Treatment	Radiation interception (%)					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S_1 (I FN of June)	66.84	62.11	61.67	55.92	49.29	39.29
S_2 (II FN of June)	64.91	61.59	60.70	55.13	48.45	38.45
S_3 (I FN of July)	63.47	60.25	60.60	54.80	47.15	37.99
S_4 (II FN of July)	62.48	59.93	57.75	53.10	46.99	36.16
B) Varieties						
V_1 (JS-335)	62.61	63.02	61.52	54.84	48.26	37.01
V_2 (MACS-450)	64.56	59.19	57.76	54.83	47.42	38.05
V_3 (DS-228)	66.11	60.70	61.25	54.53	48.23	38.85
GM	64.43	60.97	60.18	54.74	47.97	37.97
*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity						

Table 5: Radiation interception (%) encountered during soybean phenophases under sowing times and varieties (2013)

Treatment	Radiation interception (%)					
	Phenophases *					
	VG	FL	PF	SF	FSD	M
A) Sowing times						
S_1 (I FN of June)	78.32	71.31	67.83	60.95	59.04	53.77
S_2 (II FN of June)	77.07	67.62	67.38	56.78	55.58	52.42
S_3 (I FN of July)	76.61	66.29	66.63	55.49	60.17	51.08
S_4 (II FN of July)	75.95	62.28	65.44	55.32	57.34	50.02
B) Varieties						
V_1 (JS-335)	77.05	68.30	66.66	57.01	59.08	54.27
V_2 (MACS-450)	76.44	67.10	67.08	58.05	55.84	49.81
V_3 (DS-228)	77.48	65.22	66.72	56.35	59.17	51.39
GM	76.99	66.87	66.82	57.14	58.03	51.82
*VG-Vegetative stage, FL-Flowering, PF-Pod formation, SF-Seed formation, FSD-Full seed development, M-Physiological Maturity						

Table 6: Seed, straw, biological yield (pooled) and harvest index as influenced by sowing times and varieties (2012 and 2013)

Treatment	Seed yield (q ha^{-1})		Pooled	Straw yield (q ha^{-1})		Pooled	Biological yield (q ha^{-1})		Pooled	Harvest Index (%)		Mean
A) Sowing times	2012	2013		2012	2013		2012	2013		2012	2013	
S_1 (I FN of June)	22.87	29.79	26.33	28.63	36.62	32.63	59.48	54.58	57.03	38.44	54.58	46.51
S_2 (II FN of June)	21.39	27.74	24.56	28.49	34.69	31.59	56.08	54.04	55.06	38.13	51.33	44.73
S_3 (I FN of July)	18.06	25.69	21.87	26.71	33.52	30.12	51.58	51.43	51.51	35.01	49.95	42.48
S_4 (II FN of July)	15.47	23.61	19.54	26.97	32.38	29.68	47.86	48.33	48.09	32.33	48.86	40.60
S. Em ±	0.21	0.27	0.15	1.24	0.56	0.85	0.53	1.42	0.74	0.60	1.19	
C.D. at 5%	0.68	0.85	0.47	NS	1.81	NS	1.70	4.54	2.35	1.91	3.82	
B) Varieties												
V_1 (JS-335)	15.38	24.38	19.88	27.34	31.90	29.62	47.28	49.09	48.19	32.53	49.66	41.10
V_2 (MACS-450)	19.46	26.70	23.08	28.88	35.75	32.31	55.21	53.02	54.11	35.25	50.37	42.81
V_3 (DS-228)	23.50	29.04	26.27	26.89	35.26	31.07	58.76	54.18	56.47	39.99	53.60	46.80
S. Em ±	0.23	0.24	0.16	0.59	0.57	0.44	0.58	0.75	0.43	0.47	0.68	
C.D. at 5%	0.68	0.69	0.46	NS	1.65	1.29	1.70	2.19	1.05	1.37	1.97	
Interaction (AxB)												
S. Em ±	0.46	0.47	0.31	1.18	1.13	0.40	1.16	1.50	0.86	0.94	1.35	
C.D. at 5%	1.35	NS	0.91	NS	NS	NS	3.40	NS	NS	2.74	NS	
GM	19.45	26.71	23.08	27.70	34.30	31.00	53.75	52.10	52.92	35.70	51.27	43.49

4. Conclusion

The present experiment was laid out in split plot design with four sowing dates (15, 30 June and 13, 30 July) and varieties (JS 335, MACS-450 and DS-228) replicated four times. The results indicate that maximum production of soybean can be achieved if sowing is done in I FN of June and variety DS-228 gave the highest yield. The best combination of sowing date and variety was found to be in I FN of June and variety DS-228. Based on the results it was concluded that thermal use efficiency in terms of seed yield and biomass yield was higher with DS-228 (V_3) followed by MACS-450 (V_2) and JS-335 (V_1) during both the years 2012 and 2013.

5. References

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