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Studies on sowing environment for sustainable production of *rabi* sorghum (*Sorghum bicolour* L.) Under climate change situation in scarcity zone of Maharashtra

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Abstract
An experiment was conducted at Research farm, Zonal Agriculture Research Station, Solapur for five years (2013-14 to 2017-18) in *rabi* on sorghum entitled as "Studies on Sowing Environment for Sustainable Production in *Rab*i Sorghum (*Sorghum bicolour* L.) Under Climate Change Situation in Scarcity Zone of Maharashtra." to find out most optimum meteorological week for sowing sorghum in *rabi* season, to study the relationship between meteorological parameters and yield by using four different sowing windows. The results were obtained from the experiment, it was found that *rabi* sorghum sown at MW 40 (01-07 Oct) produced maximum pooled grain yield (1204.2 kg ha^{-1}), fodder (2477.1 kg ha^{-1}) and total monetary returns (Rs.35749 ha^{-1}). Among the varieties, M-35-1 was produced significantly higher grain yield (1056.8 kg ha^{-1}), fodder yield (2283.6 kg ha^{-1}) and total monetary returns (Rs.31852 ha^{-1}) over the other variety. The meteorological studies showed that the mean CUM and MUE recorded by sorghum crop was 211 mm and 4.5 kg ha^{-1}mm. The highest CUM was recorded by S_1 sown crop (233 mm) however the MUE was recorded by S_3 sown crop (5.8 kg ha^{-1}mm). This indicated that S_3 sown crop (*Chitra Nakshtras*) utilized moisture more efficiently than other dates of sowing. Among the variety M-35-1 recorded maximum mean CUM (220 mm) and MUE (4.8 ha^{-1}mm) than other varieties. The number of days required to attain physiological maturity and growing degree days were higher in S_3 sown crop. Among the varieties it is higher in M35-1 than Mauli and Yashoda. In case of RUE initially values were low, it increases up to 84 DAS (i.e. up to 50 percent flowering to soft dough stage) further it decreases in all most all the sowing dates.

Keywords: *Sorghum Bicolour*, environment, Maharashtra

Introduction
Sorghum (*Sorghum bicolor* L) is a staple grain crop in India and many countries of central Africa. It is an important dryland crop grown under erratic rainfall conditions. It is less sensitive to weather changes for longer period. With varying uncertain seasonal conditions, extreme variation in varietal performances is a serious matter for growers. The tolerance conditions are of prime importance than mere high yield potential under regular adequate water supplies. Broadly, there is a need to identify and study the major limiting climatic and physiological factors for agronomic aspects of different crops, crop growth stages and farming system in adjusting with new approaches for optimum utilization of the existing resources. Since sorghum is cultivated majorly as a rainfed crop, its productivity is significantly influenced by climatic elements (Srivastava *et al*., 2010) [10]. Decline in sorghum productivity in future climate change scenarios at different locations of India was primarily attributed to reduction in crop growth period with increase in temperature (Boomiraj *et al*., 2012) [2]. Pramod *et al*. (2017) [9] used various adaptation strategies *viz* change in sowing dates to minimize the yield reduction in wheat in India. In India, sorghum is extensively produced and both hybrid and improved varieties are taken on large scale. India is the third largest producer in the world. Among the cereals in India, sorghum ranks third, next to rice and wheat. By keeping in view, this experiment was conducted to study suitable variety under Suitable weather condition for optimum production and to identify the suitable sowing date and variety for better growth and yield of sorghum crop.

Planting date affects not only the time from sowing to flowering but time from flowering to physiological maturity of grain sorghum (Clark, 1997) [3].

Materials and Method

The experiment was carried out for five years during the rabi season from 2014 to 2018 at Dry Farming Research Station, Solapur (17.65º N 75º 90' E and 483.6 m MSL) on medium black soil (60 cm soil depth). The experiment was laid out in split plot design with four replications. Treatments were comprised of four sowing dates i.e. S_1: MW 36 (Sept.03-09) *Purva nakshtra*, S_2: MW 38 (Sept.17-23) *Uttara nakshtra*, S_3: MW 40 (Oct.01-07) *Hasta nakshtra*, S_4: MW 40 (Oct.15-21) *Chitra nakshtra*. Three sorghum genotypes i.e. V_1: M-35-1, V_2: Mauli and V_3: Yashoda were sown at spacing 45cm×15cm. The sowing of seed was done by dibbling method on respective date of sowing. Recommended packages of practices like thinning, weeding, application of recommended dose of fertilizer and pesticide were uniformly followed. Observations were recorded on five plants randomly selected per treatment. The soil of the experimental site was low in organic carbon (0.34%), medium in phosphorus (17.7 kg ha^{-1}) and high in potash content (542 kg ha^{-1}) with neutral pH (7.1). The crop was fertilized with 50:25:0 kg NPK ha^{-1}.

Results and Discussion

Growth and development of crop is influenced by environmental conditions such as temperature, radiation and photoperiod (Friend, 1966) [5]. The significant difference was recorded with different interval of sowing in respect of grain yield, monetary returns, CUM, MUE, Tmax, Tmin etc. The data on mean grain yield indicated that among the sowing dates the crop sown in third sowing date 40 MW (01-07 Oct) recorded significantly highest grain yield (1204.2 kg ha-1) and total monetary returns (Rs.35749 ha-1). These results are in concurrence with the findings of Hulihalli *et al*. (2016). Lowest grain yield was observed in fourth sowing 42 MW (15-21 Oct). Among the varieties, M-35-1 was produced significantly higher grain yield (1056.8 kg ha^{-1}) and total monetary returns (Rs.31852 ha^{-1}) as compared to other varieties. Similar results were reported by Jadhav *et al*. (2010) [7], Mokashi *et al*. (2008) [8] and Umrani *et al*. (1988) [11]. Also yield components and grain yield of the sorghum where largely influenced by the date of planting, maturity of hybrids groups and locations of the experimental site were observed by Bandiougou (2012) [1]. In case of fodder yield sowing of grain sorghum on S_3- 40 MW (01-07 Oct) registered significantly higher fodder yield (2477.1 kg ha^{-1}) followed by S_2- MW 38 (2198 kg ha^{-1}), S_1- 36 MW (2044.4 kg ha^{-1}) and S_4 -42 MW (1321.3 kg ha^{-1}) respectively. Delayed sowing of sorghum noted lower grain yields. On the basis of pooled data, it was calculated that M-35-1 was produced significantly fodder yield (2283.6 kg ha^{-1}) over the other variety (Table 2). The mean CUM and MUE recorded by sorghum crop was 211 mm and 4.5 kg ha^{-1}mm. The highest CUM was recorded by S_1 sown crop (233 mm) however the MUE was recorded by S3 sown crop (5.8 kg ha^{-1}mm). S_3 sown crop (Chitra Nakshtras) utilized moisture more efficiently than other dates of sowing. (Table 4). The RUE from different treatments are presented in Table 5. Initially the RUE values were low it increases up to 84 DAS i.e. up to 50 percent flowering to soft dough stage further it decreases in all most all the sowing dates and varieties. Changing planting date could effluence on growth process with changing environment temperature (Dehghan, 2007) [4]. The Growing degree days were higher in S_3 sown crop. Among the varieties it is higher in M35-1 than Mauli and Yashoda. This is due to more duration required by S_3 sown crop and M-35-1 variety. The Highest GDD i.e. 1350 was recorded by the S_3 sown crop (MW 40 -Oct. 01-07, Hasta nakshtra). (Table 6).

Table 1: Pooled grain yield (kg ha^{-1}) of *rabi* sorghum as influenced by sowing dates and varieties (2013-14 to 2017-18).

Treatment	2013-14	2014-15	2015-16	2016-17	2017-18	Pooled	SYI
Main=Sowing dates							
S_1 = MW 36 (Sept.03-09) *Purva nakshtra*	1062.0	1706.5	716.1	793.9	508.1	957.3	0.29
S_2 = MW 38 (Sept.17-23) *Uttara nakshtra*	1095.0	1747.8	803.2	897.4	618.2	1032.3	0.34
S_3 = MW 40 (Oct. 01-07) *Hasta nakshtra*	1371.5	1876.2	886.4	1042.4	844.4	1204.2	0.41
S_4 = MW 42 (Oct.15-21) *Chitra nakshtra*	854.7	1110.6	326.5	480.9	434.0	641.3	0.28
Mean	1095.8	1610.3	683.0	803.7	601.2	958.8	
Sub=Varieties							
V_1 = Maldandi (M-35-1)	1216.7	1729.0	795.0	884.3	659.1	1056.8	0.34
V_2 = Mauli	1105.5	1573.9	644.2	770.2	573.2	933.4	0.30
V_3 = Yashoda	965.2	1527.9	609.9	756.4	571.2	886.1	0.28
Mean	1095.8	1610.3	683.0	803.7	601.2	958.8	
S.E.± (Sowing dates)	69.51	52.0	59.0	57.1	44.4	41.2	
C.D. at 5 %	222.4	166.3	188.6	182.6	142.1	127.0	
S.E.± (Varieties)	63.9	44.7	32.9	33.3	23.9	18.9	
C.D. at 5 %	186.6	130.5	96.0	97.1	69.6	54.5	
S.E.± (SD X V)	127.9	89.4	65.8	66.5	47.7	37.8	
C.D. at 5 %	NS	NS	NS	NS	NS	NS	

Table 2: Pooled fodder yield (kg ha^{-1}) of *rabi* sorghum as influenced by sowing dates and varieties (2013-14 to 2017-18).

Treatment	2013-14	2014-15	2015-16	2016-17	2017-18	Pooled	SYI
Main=Sowing dates							
S_1 = MW 36 (Sept.03-09) *Purva nakshtra*	2684.8	3094.6	1741.8	1500.3	1200.3	2044.4	0.40
S_2 = MW 38 (Sept.17-23) *Uttara nakshtra*	2838.9	3248.7	1895.9	1642.9	1363.6	2198.0	0.43
S_3 = MW 40 (Oct. 01-07) *Hasta nakshtra*	3273.9	3683.7	2176.1	1711.3	1540.2	2477.1	0.41
S_4 = MW 42 (Oct.15-21) *Chitra nakshtra*	1654.5	2064.2	711.5	1116.0	1060.2	1321.3	0.38
Mean	2613.1	3022.8	1631.3	1492.7	1291.1	2010.2	
Sub=Varieties							

V_1 = Maldandi	2872.5	3282.2	1879.4	1811.9	1572.2	2283.6	0.47
V_2 = Mauli	2660.3	3070.0	1717.3	1471.1	1275.1	2038.8	0.41
V_3 = Yashoda	2306.4	2716.1	1297.3	1195.0	1026.0	1708.1	0.35
Mean	2613.1	3022.8	1631.3	1492.7	1291.1	2010.2	
S.E.+ (Sowing dates)	136.6	136.6	147.2	106.6	94.6	111.4	
C.D. at 5 %	437.1	437.1	470.8	341.2	302.7	343.3	
S.E.+ (Varieties)	103.2	103.2	100.0	69.6	61.7	35.1	
C.D. at 5 %	301.2	301.2	291.9	203.1	180.0	101.2	
S.E.+ (SD X V)	206.4	206.4	200.0	139.2	123.3	70.2	
C.D. at 5 %	NS	NS	NS	NS	NS	NS	

Table 3: Pooled total monetary returns (Rs. ha $^{-1}$) of *rabi* sorghum by sowing dates and varieties (2013-14 to 2017-18).

Treatment	2013-14	2014-15	2015-16	2016-17	2017-18	Pooled	SYI
Main=Sowing dates							
S_1 = MW 36 (Sept.03-09) *Purva nakshtra*	35224	39373	14607	27349	18704	27051	0.42
S_2 = MW 38 (Sept.17-23) *Uttara nakshtra*	36743	40771	16560	30649	22273	29399	0.48
S_3 = MW 40 (Oct. 01-07) *Hasta nakshtra*	44331	44775	26211	34617	28810	35749	0.61
S_4 = MW 42 (Oct.15-21) *Chitra nakshtra*	25312	26187	10860	17603	16152	19223	0.49
Mean	35403	37776	17059	27555	21485	27856	
Sub=Varieties							
V_1 = Maldandi	39246	44075	20432	31167	24338	31852	0.50
V_2 = Mauli	36068	35811	16505	26611	20706	27140	0.51
V_3 = Yashoda	30893	33443	14241	24886	19410	24575	0.50
Mean	35403	37776	17059	27555	21485	27856	
S.E.+ (Sowing dates)	1972.6	1121.0	1051.4	1665.7	1329.7	968.8	
C.D. at 5 %	6310.8	3586.2	3363.6	5328.9	4254.0	2985.3	
S.E.+ (Varieties)	1608.7	699.0	594.4	914.7	667.5	471.1	
C.D. at 5 %	4695.6	2040.2	1734.9	2669.7	1948.3	1357.2	
S.E.+ (SD X V)	3217.5	1398.0	1188.7	1829.3	1335.0	942.3	
C.D. at 5 %	NS	NS	NS	NS	NS	NS	

Table 4: Mean CUM and MUE as influenced by sowing time in *rabi* sorghum (2013-14 to 2017- 18).

Sowing	CUM (mm)				MUE (kg ha^{-1} mm)			
Time	M-35-1	Mauli	Yashoda	Mean	M-35-1	Mauli	Yashoda	Mean
S_1	231	229	239	233	4.5	4.1	3.7	4.1
S_2	225	205	234	221	4.9	5.2	4.0	4.7
S_3	229	185	216	210	5.5	6.4	5.4	5.8
S_4	195	160	181	179	4.2	3.4	3.1	3.6
Mean	220	195	218	211	4.8	4.8	4.0	4.5

CUM: Consumptive Use of Moisture
MUE: Moisture Use Efficiency

Table 5: Mean Radiation use efficiency (g MJ^{-1}) as influenced by varieties and sowing dates in sorghum (2013-14 to 2017-18)

		S1			S2			S3			S4		
MW	DAS	MAU	YESH	M.35-1	MAU	YESH	M.35-1	MAU	YESH	M.35-1	MAU	YESH	M.35-1
36	SO	SOW	SOW	SOW	-	-	-	-	-	-	-	-	-
38	14	0.44	0.28	0.30	-	-	-	-	-	-	-	-	-
40	28	0.86	0.63	0.74	0.28	0.33	0.31	-	-	-	-	-	-
42	42	1.58	1.45	1.37	0.72	0.45	0.55	-	-	-	-	-	-
44	56	2.42	1.86	2.17	1.16	1.00	0.92	0.62	0.40	0.50	0.11	0.16	0.17
46	70	2.48	2.32	2.31	2.26	1.67	1.99	1.35	1.21	1.14	0.54	0.31	0.41
48	84	2.53	2.38	2.50	2.32	2.14	2.12	2.45	1.88	2.20	0.91	0.77	0.70
50	98	1.63	1.45	1.52	1.65	2.19	2.31	2.51	1.80	2.33	2.01	1.44	1.86
51	105	1.54	0.92	1.40	1.47	2.15	2.13	2.36	1.52	2.53	2.07	1.91	1.89
1	119	1.04	-	0.91	1.38	1.61	2.09	1.65	1.04	2.35	1.39	1.96	2.09
3	133	0.95	-	0.67	0.99	-	1.60	1.57	0.48	2.31	1.21	1.92	1.90
5	147	-	-	-	0.32	-	0.91	1.06	-	1.81	0.86	0.77	0.71
6	154	-	-	-	-	-	-	0.60	-	1.59	0.62	-	-
7	161	-	-	-	-	-	-	-	-	0.33	0.45	-	-

Table 6: Mean Growing degree days required to attain phenological stages as influenced by sowing dates in *rabi* sorghum (2013-14 to 2017-18).

Sowing Time	Phenological stage							
	Emer.	3 leaf	PI	Flag leaf	50 % flowering	Soft dough	Hard dough	Phy. Maturity
S_1V_1	78	66	258	371	165	179	173	218
Cumulative	78	145	402	774	938	1118	1290	1509
S_1V_2	54	35	342	293	161	165	170	188
Cumulative	54	90	432	725	886	1050	1221	1409

S_1V_3	66	54	222	361	128	150	137	171
Cumulative	66	120	342	703	831	982	1118	1290
S2V1	80	68	252	405	171	188	167	210
Cumulative	80	148	400	805	976	1164	1331	1541
S2V2	57	40	330	284	223	175	172	179
Cumulative	57	97	427	711	934	1110	1282	1461
S2V3	50	55	236	352	118	169	131	127
Cumulative	50	105	341	693	810	979	1110	1238
S3V1	72	67	258	501	201	201	179	221
Cumulative	72	139	397	898	1098	1299	1478	1699
S_3V_2	66	54	222	447	157	150	137	171
Cumulative	66	120	342	790	946	1097	1234	1405
S_3V_3	66	67	210	398	146	166	120	133
Cumulative	66	133	343	742	887	1054	1174	1306
S_4V_1	66	68	197	344	122	149	158	190
Cumulative	66	134	330	674	797	946	1103	1294
S_4V_2	64	66	185	335	109	139	137	175
Cumulative	64	130	315	650	759	898	1035	1210
S_4V_3	48	53	173	302	97	114	112	150
Cumulative	48	101	274	575	672	786	898	1049

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