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Impact of climate change on sorghum productivity in India and its adaptation strategies

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ABSTRACT

Future climate change projections for India indicate distinct rise in temperature and increased variability in rainfall. This study aims to assess the impact of climate change on sorghum productivity in India in future climatic periods (2025, 2050 and 2075) using DSSAT-sorghum and suggest adaptation strategies to negate the negative impact of climate change on sorghum productivity in the future climates. Three CMIP-5 climate models (GFDL-ESM2M, MIROC5 and NorESM1-M) generated weather data for three future periods were used at various locations for *kharif* (Akola, Dharwad, Surat and Udaipur) and *rabi* (Bijapur, Dharwad, Rahuri and Solapur) seasons to simulate sorghum yields. Projected changes in day-night temperatures and rainfall during *kharif* and *rabi* growing seasons at these locations are diverse both in direction and magnitude. Increasing trend in rainfall is observed during both crop seasons towards the end of 21st century. Sorghum crop is likely to experience warmer temperature in the second half of the century and rise in minimum temperature is more explicit than maximum temperature at all the locations. Location specific management options can be adopted to mitigate the negative impacts of the change in climate in future projected scenarios, as they are found beneficial.

Keywords : Climate change, DSSAT, sorghum, adaptation strategies, India

Sorghum is one of the major cereal crop grown mostly under rainfed condition and it continued to be main staple food for marginal farmers of developing countries in Asia and Africa (Murthy *et al.,* 2007). Due to its higher drought tolerance over other cereal crops, sorghum is highly suitable to Semi Arid Tropic (SAT) crop production system (Ludlow and Muchow, 1990). In India 5.45 million tons (3.14 million tons during *rabi* and 2.31 million tons during *kharif* seasons) of sorghum is produced from 6.18 million hectares (DACNET 2016). The sorghum productivity in India is far low (864 kg ha^{-1}) compared to global average (1481 kg ha^{-1}) (FAOSTAT, 2016). Since sorghum is cultivated majorly as a rainfed crop, its productivity is significantly influenced by climatic elements (Srivastava *et al.,* 2010). Grain sorghum yield is extremely influenced by crop management practices, growing–season rainfall amount and its distribution, soil water content at planting, plant-available water and other climatic conditions (Assefa *et al.,* 2010). Varshneya *et al.*, (2004) pointed out that sorghum phenology is inversely proportional to change in temperature and grain yield is directly proportional to change in rainfall. Sandeep *et al.*, (2017) have reported increasing trend in the water requirement of sorghum over majority of sorghum growing regions both in *kharif* and *rabi* season during 2050 to 2080 inspite of increasing trend in rainfall.

Crop growth simulation models (CGSMs) are widely used to study the impact of climate change on crop productivity. Climate change impact studies involving *rabi* sorghum projected a decline in yield up to 7 per cent by 2020, up to 11 per cent by 2050 and up to 32 per cent by 2080 (Srivastava *et al.,* 2010) over the base period 1978-1999. 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). Pramod *et al.* (2017) used various adaptation strategies viz change in sowing dates, applying additional irrigation and fertilizer to minimize the yield reduction in wheat in India. In this background an attempts has been made to study the impact of climate change on sorghum yield and to quantity the benefits of adaptation strategies like changing sowing time, irrigation scheduling on the productivity of sorghum for *kharif* and

Table 1: Geographic and agro-climatic features of different sites

Season	Location	Latitude	Longitude	Altitude (AMSL)	Seasonal rainfall (mm)	Seasonal average Tmax (°C)	Seasonal average Tmin (°C)
Kharif	Akola	20.70	77.02	296	712	33.2	24.1
	Dharwad	15.27	75.05	731	478	29.5	21.1
	Surat	21.10	72.49	12	1393	33.2	25.4
	Udaipur	24.35	73.42	573	603	32.6	23.2
Rabi	Bijapur	16.49	75.42	614	186	31.2	18.3
	Dharwad	15.27	75.05	731	204	30.3	17.8
	Rahuri	19.23	74.38	516	156	31.2	14.4
	Solapur	17.39	75.54	474	121	32.1	16.4

rabi seasons in future climate scenarios (2025, 2050 and 2075) using DSSAT-Sorghum model.

MATERIALS AND METHODS

Study area

In the present study four representative locations were selected each for *kharif* and *rabi* seasons. The major *kharif* sorghum growing regions are extended between the states of Rajasthan (North) to Karnataka (South). We selected Akola (Central), Dharwad (South), Surat (West) and Udaipur (North) for *kharif* season. The major *rabi* sorghum growing regions are confined to Deccan Plateau, Western and Central India. We selected Rahuri, Solapur, Dharwad and Bijapur (South) for *rabi* seasons. These locations are selected on the basis of data availability and their climate/soil regimes. The geographical/seasonal climatic characteristics and soil/ experimental details of the selected locations are furnished in Table1 and Table 2 respectively. Site wise daily weather data on maximum and minimum temperature, rainfall and sunshine hours apart from crop and soil data were collected and used in DSSAT-Sorghum model simulations. Replicated trials widely cultivated Indian sorghum genotypes (CSH-9, CSH-16) during the *kharif* and (M-35-1) during the *rabi* were conducted at all the locations.

CERES – Sorghum model

CERES- Sorghum, a process-based and management-oriented crop simulation model embedded in Decision Support for Agrotechnology Transfer (DSSAT) platform was used for sorghum yield simulations.The genotypic coefficients for various sorghum cultivars were chosen by repeated iterations using field experimental data for the different locations until a close match between simulated and observed yield was attained. Model efficiency was determined by comparing observed and simulated yields using statistical tools like root mean square error (RMSE) and D-index.

Climate change projections and adaptation strategies

The projected daily weather datasets were sourced from three global general circulation models (GCMs) from coupled model inter comparison project-5(CMIP-5) in RCP 4.5 scenarios viz., GFDL-ESM2M, MIROC5 and NorESM1-M, which were found suitable for Indian conditions (Pramod *et al.,* 2017) for the years 2025, 2050 and 2075 for the selected locations. The projected CO_2 concentrations in RCP 4.5 were 440, 530 and 570 ppm by 2025, 2050 and 2075s, respectively, and were used in simulating the future sorghum yields, while measured concentration was used for the baseline period. The projected daily weather data viz., daily rainfall, maximum temperature (T_{max}), minimum temperature (T_{min}) and solar radiation from GCMs,were sourced from MarkSim DSSAT weather file generator (http://gisweb.ciat.cgiar.org/MarkSimGCM/).

In the present study, three crop management options viz., (1) six sowing time options (15, 10, 5 days ahead and 5, 10, 15 days delayed relative to normal sowing time) as the first low-cost option tried and to chose the one which provides the highest yield, (2) one additional irrigation of 50 mm at 45-60 days after sowing (DAS) and (3) change in sowing time combined with additional irrigation, were tested as adaptation strategies to sustain sorghum productivity for *kharif* and *rabi* seasons in future climates.The net effect of each adaptation strategy was assessed in terms of relative yield as

$$\text{Relative yield} = \left(\frac{Y_{fa} - Y_b}{Y_b}\right) * 100$$

Table 2: Soil and experimental details at different sites

Season	Location	Crop growing period	Soil type	Soil pH	Bulk Density	Data source	Selected cultivars	Data period	Fertilizer schedule
Kharif	Akola	1-10 July to 15-25 October	Clay Loam	7.8	1.37	Long Term Fertilizer Experiment (LTFE)	CSH-9	2005-2009	80:40:40 (NPK at DOS)
	Dharwad	1-8 July to 15-25 October	Medium deep black (Clay)	7.8	1.31	AICRP on Sorghum	CSH-16	2010-2014	80:40:40 (NPK at DOS)
	Surat	15-30 June to 1-10 October	Deep black	7.8	1.38	AICRP on Sorghum	CSH-16	2010-2014	80:40:40 (NPK at DOS)
	Udaipur	1-8 July to 15-25 October	Sandy clay loam	7.9	1.46	AICRP on Sorghum	CSH-16	2010-2014	80:40:40 (NPK at DOS)
Rabi	Bijapur	20-30 September to 1-10 February	Clay	8.3	1.36	AICRP on Agrometeorology	M-35-1	2007-2014	50:25:00 (NPK at DOS)
	Dharwad	1-15 October to 1-10 February	Medium deep black (Clay)	7.8	1.31	AICRP on Sorghum	M-35-1	2010-2014	60:30:00 (NPK at DOS)
	Rahuri	20-30 September to 1-10 February	Clay	8.4	1.49	AICRP on Sorghum	M-35-1	2010-2014	60:30:00 (NPK at DOS)
	Solapur	15-25 October to 15-25 February	Shallow and medium	8.6	1.39	AICRP on Agrometeorology	M-35-1	2007-2014	50:25:00 (NPK at DOS)

Where Y_{fa} indicates future yield due to adaptation and Y_b indicates baseline yield without any adaptation. The combination(s), which gave the highest relative yield at each site in each scenario, was considered as the best suitable adaptation option (Pramod *et al.,* 2017). While simulating crop yields in future climates technological advancements in crop management, as well as impacts of pest and diseases on crop production, are not considered.

RESULTS AND DISCUSSION

Calibration of CERES-Sorghum

The CERES-Sorghum model was calibrated for different sorghum cultivars (CSH-9, CHS 16) for *kharif* and (M-35-1) for *rabi* seasons based on data from field experiments carried out at respective experimental locations. Cultivar specific genotypic coefficients were estimated by the GENCALC software embedded in DSSAT v4.6 and the calibrated genetic coefficients of various sorghum cultivars at respective sites are presented in Table 3.The CERES-Sorghum model satisfactorily simulated the phenology and grain yield of sorghum cultivars in close match with observed values at different locations for both *kharif* and *rabi* seasons (Table 4). The differences with measured values are well within acceptable error level as indicated by a very high value of D-Index and acceptable RMSE values.

Climate change projections at different sites

The average percentage change in T_{max},T_{min} and rainfall projected by three models over baseline during the sorghum growing seasons (*kharif* and *rabi*) in 2025, 2050 and 2075 at four respective experimental sites are summarized in Table 5. The rise in T_{min} more severe in comparison with T_{max} over all the locations in future climatic periods during both (*kharif* and *rabi*) crop growing seasons. Rainfall (*kharif* and *rabi* seasons) is projected to be below normal during 2025 and expected to increase towards 2075 at all locations. Sorghum crop is likely to receive more rainfall at Dharwad (+18% and +28% during *kharif* and *rabi* crop seasons respectively) by 2075. The *kharif* season sorghum crop experience warmest day and night temperatures at Dharwad (+11% and +14%) and Udaipur (+10% and 17%), while *rabi* season sorghum crop may experience warmest daytime temperature at Bijapur (+10%) followed by Solapur (+10%) and warmest nights at Dharwad (+20%) followed by Bijapur (+18%) towards the end of 21st century.

Table 3: Genotypic coefficients used for selected sorghum cultivars for rainy and post rainy seasons

Station	Variety	P1	P2	P2O	P2R	PANTH	P3	P4	P5	PHINT	G1	G2
Rainy season												
Akola	CSH-9	680	100	16.5	125	617.5	152.5	81.5	500	49	20	6
Dharwad	CSH-16	300.5	102	16	270	617.5	152.5	81.5	700	49	18	4.5
Surat	CSH-16	470.5	102	16	170	617.5	152.5	81.5	700	49	22	6
Udaipur	CSH-16	505	102	17	295	617.5	152.5	81.5	600	49	22	6
Post rainy season												
Bijapur	M-35-1	236	102	17	95.6	617.5	152.5	81.5	540	49	12	6
Dharwad	M-35-1	310	102	16	195.6	617.5	152.5	81.5	540	49	22	6
Rahuri	M-35-1	305	102	13	55.6	617.5	152.5	81.5	446	49	22	6
Solapur	M-35-1	280	102	15	155.6	617.5	152.5	81.5	540	49	13	6

P1-Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above TBASE during which the plant is not responsive to changes in photoperiod, P2-Thermal time from the end of the juvenile stage to tassel initiation under short days (degree days above TBASE), P2O-Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate, P2R- Extent to which phasic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P2O, PANTH-Thermal time from the end of tassel initiation to anthesis (degree days above TBASE), P3-Thermal time from to end of flag leaf expansion to anthesis (degree days above TBASE), P4-Thermal time from anthesis to beginning grain filling (degree days above TBASE), P5-Thermal time from beginning of grain filling to physiological maturity (degree days above TBASE), PHINT-Phylochron interval; the interval in thermal time between successive leaf tip appearances (degree days), G1-Scaler for relative leaf size, G2- Scaler for partitioning of assimilates to the panicle (head).

Simulated future sorghum yield without any adaptation strategies

The future sorghum yields for *kharif* and *rabi* seasons simulated using different climate change scenarios (GFDL-ESM2M, MIROC5, and NorESM1-M) with the existing fertilizer (100% NPK) at each experimental site without any adaptation strategies indicate that during the first quarter of the 21st century (2025) the mean relative yield is achieved at Akola and Dharwad with existing crop management practices, while by middle of the 21st century (2050) it is confined only to Akola (Table 6). By the end of this century (2075) *kharif* sorghum yields are declined at all the selected locations. From Table 5 it is evident that the temperature is above normal over all the locations except during 2025, 2050 at Akola and during 2025 at Dharwad. Due to the increase in temperature as discussed in earlier section, the length of growing period is declining resulting in reduced yields. A decline of 4 days and 2 days in crop duration is simulated at Udaipur and Surat respectively and it causes a drop in yield about 10 per cent at Udaipur and 4 per cent at Surat in 2025. In 2050 the crop duration decreased up to 2 days with reduced yield of 13 per cent at Udaipur, 7 days with reduced yield about 6 per cent at Dharwad and Surat. Further a marked decline in growing period is simulated at Dharwad (8 days),followed by Udaipur (7 days), Surat (7 days) and Akola (5 days) in 2075. A decline in yield is noticed about 3 per cent at Akola, 14 per cent at Dharwad, 3 per cent at Surat and 13 per cent at Udaipur in 2075.

The *rabi* season sorghum yield (Table 6) and length of growing period (Table 5) also shows signs of decreasing trend in future climatic scenarios over all the locations except Bijapur and Rahuri during 2050. The average temperature during the crop growing seasons is above normal in future climatic scenarios over all the locations. A marked decrease of crop duration at Dharwad (8 days) followed by Bijapur (7 days),Rahuri (4 days) and Solapur (4 days) in 2025 is projected. A reduction in yield about 20 per centat Bijapur, 16 per cent at Dharwad, 10 per cent at Rahuri and 13 per cent at Solapur is simulated in 2025. The crop duration is further decreased by 9 days and 2 days at Dharwad and Solapur respectively in 2050 with a decline in yield by 22 per cent at Dharwad and 4 per cent at Solapur. A further decrease in season length is simulated up to 9 days at Dharwad and Bijapur as well as 5 days at Rahuri and Solapur in 2075. Yield reductions are simulated about 22 per cent at Bijapur, 23 per cent at Dharwad, 7 per cent at Rahuri

Table 4: Observed and simulated crop phenology and grain yields during baseline period

Season	Parameter	Station	Mean		Standard Deviation		D-Index	RMSE
			Observed	Estimated	Observed	Estimated		
Kharif	Anthesis day	Akola	74	75	3.57	2.07	0.87	1.84
		Dharwad	71	73	1.3	1.6	0.7	1.8
		Surat	64	64	2	2.07	0.8	1.5
		Udaipur	74	76	6.44	4.39	0.86	3.8
	Maturity day	Akola	112	108	4.32	3.3	0.59	4.1
		Dharwad	111	112	2.3	3.67	0.78	2.4
		Surat	105	103	1.3	2.38	0.68	2.7
		Udaipur	114	113	1.92	4.5	0.79	2.5
	Yield (kg ha^{-1})	Akola	4143	3672	980	699	0.81	734.2
		Dharwad	4354	4150	946	614	0.77	646.5
		Surat	3493	3291	310	256	0.65	320.2
		Udaipur	4602	4406	1356	668	0.74	650.6
Rabi	Anthesis day	Bijapur	62	61	1.58	1.67	0.66	2.16
		Dharwad	65	66	2.65	2.06	0.77	1.94
		Rahuri	64	65	2.58	3.2	0.85	1.8
		Solapur	59	56	3.7	1.8	0.62	4.7
	Maturity day	Bijapur	105	102	2.56	2.73	0.67	3.82
		Dharwad	109	112	3.11	3.81	0.77	3.4
		Rahuri	109	108	3.16	2.55	0.75	2.55
		Solapur	98	97	3.38	3.2	0.59	4.2
	Yield (kg ha^{-1})	Bijapur	1378	1573	507	567	0.72	441.8
		Dharwad	2832	2692	1304	618	0.8	754.7
		Rahuri	2088	2346	386	356	0.61	436.4
		Solapur	1034	1376	221	143	0.51	243.2

and 14 per cent at Solapur in 2075.

Impact of adaptation strategies

The average magnitude of improvement (%) in grain yield (mean of the three selected projected scenarios) by the various adaptation strategies in future climatic periods for *kharif* and *rabi* sorghum are furnished in Table 6. The influence of delayed sowing is found negatively on *kharif* and *rabi* yield over all the locations in future climatic scenarios, so the results are not provided here.

***Kharif crop*:** The impact of six different sowing dates (three early and three late sowings at an interval of five days) with respect to the normal date of sowing (DOS) at each experimental site was assessed. The application of additional irrigation with normal DOS is not found beneficial (Table 6). Among the four sites, significant improvement and targeted *kharif* sorghum yield was attained at Surat during all the three future periods and over Akola in 2075 when sowing was advanced compared to the normal DOS. Due to the relatively small change in mean temperature the targeted yield is attained with normal DOS without any adaptation strategies at Akola in 2025 and 2050 and at Dharwad in 2025. The advancement of sowing date is able to achieve the targeted yield by alleviating temperature stress and ensure the availability of moisture in rainfed condition at Akola in 2075 and at Surat in all the future periods. Due to the comparatively steep rise in temperature over Udaipur in all the future periods and at Dharwad in 2050 & 2075, the advancement of sowing time combined with an extra irrigation of 50 mm (45-60 DAS) is required to attain the targeted productivity.

Table 5: Mean percentage change from the three selected models in T_{max}, T_{min} and rainfall over baseline during sorghum growing season in future climatic scenarios

Kharif season						*Rabi* season					
Location	Weather variable	Normal value	2025	2050	2075	Location	Weather variable	Normal value	2025	2050	2075
Akola	Rainfall (mm)	592	-2	4	3	**Bijapur**	Rainfall (mm)	153.35	-15	10	15
	Tmax (°C)	31.77	0	1	5		Tmax (°C)	30.49	10	0	11
	Tmin (°C)	23.39	3	3	9		Tmin (°C)	15.37	11	7	18
	Days to anthesis	74	2	-4	-4		Days to anthesis	62	-4	-1	-4
	Days to maturity	112	6	-2	-5		Days to maturity	105	-7	2	-9
Dharwad	Rainfall (mm)	456.4	-6	2	18	**Dharwad**	Rainfall (mm)	198.67	-21	-5	28
	Tmax (°C)	27.39	-4	7	11		Tmax (°C)	28.81	5	6	8
	Tmin (°C)	20.49	3	12	14		Tmin (°C)	15.72	12	17	20
	Days to anthesis	71	2	-3	-5		Days to anthesis	65	-4	-6	-6
	Days to maturity	111	5	-7	-8		Days to maturity	109	-8	-9	-9
Surat	Rainfall (mm)	965	0	-3	5	**Rahuri**	Rainfall (mm)	122	-21	-15	16
	Tmax (°C)	31.01	4	3	4		Tmax (°C)	30.69	9	6	8
	Tmin (°C)	26.57	6	8	9		Tmin (°C)	13.34	11	6	10
	Days to anthesis	64	0	-4	-4		Days to anthesis	64	-2	0	-2
	Days to maturity	105	-2	-7	-7		Days to maturity	109	-4	1	-5
Udaipur	Rainfall (mm)	569	-7	-5	7	**Solapur**	Rainfall (mm)	101.76	-10	-9	18
	Tmax (°C)	33.12	7	7	10		Tmax (°C)	31.59	8	9	10
	Tmin (°C)	23.75	10	11	17		Tmin (°C)	16.46	11	14	13
	Days to anthesis	74	-2	-1	-2		Days to anthesis	59	-1	-1	-2
	Days to maturity	114	-4	-2	-7		Days to maturity	98	-4	-2	-5

Table 6: Various adaptation strategies of *kharif* and *rabi* sorghum with average magnitude of advantage (% grain yield) for different climate periods

Season	Location	Normal date of sowing			Normal date of sowing with additional irrigation (45-60 DAS)			Early sowing			Early sowing with additional irrigation (45-60 DAS)		
		2025	2050	2075	2025	2050	2075	2025	2050	2075	2025	2050	2075
Kharif	Akola	5	2	-3	8	3	-1	3	4	2	13	9	3
	Dharwad	7	-6	-14	8	-3	-11	-2	-5	-7	4	8	9
	Surat	-4	-6	-3	-3	-8	-7	5	6	3	8	9	16
	Udaipur	-10	-13	-13	-9	-7	-9	0	-4	-2	11	14	7
Rabi	Bijapur	-20	12	-22	-15	18	-15	-8	14	-11	7	18	4
	Dharwad	-16	-22	-23	-11	-13	-16	-7	-8	-10	4	9	7
	Rahuri	-10	4	-7	-3	9	-5	-6	9	7	5	13	16
	Solapur	-13	-6	-14	-13	-3	-15	-5	-8	-10	5	9	4

***Rabi crop*:** Due to comparatively lower temperature stress at Bijapur and Rahuri in 2050 the targeted yield is attained in normal DOS without any adaptation strategies.The application of additional irrigation with normal DOS is found not beneficial adaptation strategy.The advancement of sowing date reduces the impact of temperature stress and facilitates to attain the targeted yield at Rahuri in 2075. Due to the higher rate of temperature stress advancement of sowing date combined with an extra irrigation of 50 mm (45-60 DAS) is required to sustain the targeted yield at Rahuri in 2025, at Bijapur in 2025 and 2075 and in all the future periods at Solapur and Dharwad (Table 6). Though adjusting sowing time is the most widely studied strategy of adaptation (White *et al.,* 2011), the impact by adjusting sowing time appears to be location specific as observed in the present study as the response is not uniform across the sites studied. The differential rise in day and night temperatures at different sites could be another reason for this response.

CONCLUSIONS

Calibrated and validated CERES-Sorghum model can be used to study the impact of climate change on sorghum yields for *kharif* and *rabi* seasons in India. Both *kharif* and *rabi* sorghum crop is likely to receive below normal rainfall in 2025 and projected to increase towards the end of the 21st century. Sorghum crop may confront with warmer temperature in the second half of the century and the rise in night time is more severe than day time temperature over all the locations during both *kharif* and *rabi* seasons. By following existing crop management practices normal *kharif* yield is achieved at Akola and Dharwad in the first quarter of 21st century and in the middle of the century it is confined only at Akola. The normal *rabi* sorghum yield is achieved in future climatic periods only at Bijapur and Rahuri during 2050. Both *kharif* and *rabi* sorghum yield is exhibiting a decreasing trend towards the end of the 21st century. Negative influences of climatic change over sorghum growing areas of India can be minimized by adapting one or a combination of management practices like adjusting sowing time, application of extra irrigation which are location specific as obtained from the present study.

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