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Variability assessment of four *kharif* sorghum genotypes under varied levels of moisture regimes and dates of sowing

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Abstract
DSSAT-CERES Sorghum model was calibrated and evaluated for four *kharif* sorghum genotypes (CSV-17, CSV-23, CSH-16 and CSH-23) using two years (*kharif* 2011 and 2012) experimental data, and then used to simulate growth and yield of same four genotypes under two moisture regimes (rainfed as stressed and irrigated as no-stressed) and three dates of sowing (15, June, 30, June and 15, July) on blacks soils of Dharwad. The study showed that variation in rainfall between years greatly affected *kharif* sorghum yield as crop experienced moisture stress during both the years, but much more during 2012 (rain deficit year) than in 2011 (above normal year), thus proving that *kharif* sorghum requires supplemental irrigation at critical stages to realize potential yields. Among different cultivars tested, CSH-16 performed well (6637 and 5174 kg ha^{-1} in stressed and non-stressed condition, respectively) compared to other genotypes across moisture regimes and dates of sowing. Among the dates of sowing, 15th June sown crop recorded higher yield both under stressed and no-stressed condition as compared to later sowing (30, June and 15, July), but the per cent yield difference between stressed and non-stressed condition were higher during 2012 (30.62 %) than 2011 (22.28 %).

Keywords: DSSAT model, moisture regimes, dates of sowing, sorghum, NTZ

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth major cereal crops in India and is grown during both *kharif* and *Rabi* seasons. It's major area is focused in the Deccan Plateau, Central and Western India apart from a few patches in Northern India. More than 90 per cent of the total area is rainfed (Sandeep *et al*. 2017) [11], and about 85 per cent of total production is concentrated in the semi-arid regions of Karnataka, Maharashtra, Telangana and Andra Pradesh (DACNET, 2016) [2].Yield gap analysis studies in sorghum have shown that the total yield gap between potential and actual for all production zones across India was 2410 kg ha^{-1} (Murthy *et al*. 2007) [9]. This suggests that sorghum crop production faces several constraints in realizing potential yield and, high temperatures and moisture stress are two major constraints in rainfed and semi-arid areas.

In Karnataka, *kharif* and *rabi* area accounts for 1.16 and 9.31 lakh ha, respectively, with a production of 1.60 lakh tonnes in *kharif* and 10.14 lakh tonnes in *rabi* season. The average productivity of *kharif* and *rabi* sorghum is 1379 and 1089 kg ha^{-1}, respectively (DACNET, 2016) [2], which suggests that *kharif* yields are higher than *rabi* yields due to SW monsoon rains during *kharif* season which makes up, on average, 70-80 % of total annual rainfall and average seasonal temperatures during this period are cooler than in *rabi*. In recent decade's area, production and productivity of *kharif* sorghum in Karnataka has declined due to introduction of cash crops (*viz*., maize, cotton), crops suited for mechanized production (*viz.*, maize, greengram, soybean) and changing food habits, among other reasons.

The production potential of any crop largely depends on adoption of agro-techniques *viz*, selection of suitable cultivars, optimum date of sowing, supplemental irrigation to overcome moisture stress, and nutrient management, among others. In this regard, given the extent of yield gap between potential and actual yields on farmers' field, providing supplemental irrigation to *kharif* sorghum at critical stages of the crop or when crop experiences moisture stress assumes greater significance to realize the potential yield. Although NTZ, on an average, receives little over 700 mm rainfall per annum and *kharif* season (June-Sept) gets bulk of it (80 %), the variability observed in amount of rainfall received over space and time, as well as between and within years in NTZ, more often than not, exposes *kharif* crops including sorghum to moisture stress, thus potential yield is not realized (Venkatesh *et al*. 2016) [15]. Therefore, crop productivity is limited by moisture availability, thus early sowing assumes greater importance even during *kharif* season for the crop to make the most of available soil moisture. Therefore, in this study we hypothesized that supplemental irrigation would be required to meet out actual crop water demand to realize potential yield of crop. Keeping these things in the view the simulation modeling study was taken up to assess the performance of selected *kharif* sorghum cultivars across three dates of sowing and two moisture regimes to quantify the effect of early or delayed sowing and moisture regimes (stressed and non-stressed) on the yield of four *kharif* sorghum cultivars.

Material and Methods

***Source of experimental data for modelling*:** Field experiment with three dates of sowing *viz*., 15, June, 30, June and 15, July, and four cultivars *viz.*,CSV-17, CSV-23, CSH-16 and CSH-23 under rainfed conditions on deep black soils of Dharwad was carried out for two seasons (*kharif* 2011 and *kharif* 2012). The data collected from this experiment on phenology (days to 50 % flowering and physiological maturity), grain yield, stover yield and total above ground biomass was used for calibration (with *kharif* 2011 data) and evaluation (with *kharif* 2012 data) of DSSAT-CERES-Sorghum model, and the results are presented and published elsewhere (Sannagoudar *et al*. 2019) [13]. Similarly, readers are directed to refer to the same paper for information on soil, crop management practices followed, inputs used and other management practices included into the model for calibration and evaluation.

Description of the Study Location: The field experiment from which the data for modeling was used, was conducted during *kharif* seasons of 2011 and 2012 under All India Coordinated Research Project (AICRP) on Sorghum at Main Agricultural Research Station, Dharwad, located at 15^0 26' North latitude, 75^0 07' East longitude, and at an altitude of 678 m above mean sea level (MSL). This station comes under the NTZ (No-8) of agro-climatic zones of Karnataka and lies between the Western Hilly Zone (Zone-9) which receives more rainfall (>1000 mm) and Northern Dry Zone (Zone-3) which receives very limited rainfall (~500 mm). The average annual rainfall of this station from 1985-2014 was 722.80 mm and of which 452.70 mm (62 % of annual total) was received during *kharif* season (June-September). However, rainfall received during *kharif* seasons of 2011 and 2012was 532.00 and 335.20 mm, respectively, representing two completely contrasting moisture regimes; *kharif* 2011 was above normal year (+ 17.52 % above long-term average) whereas, *kharif* 2012 was rain deficit (-35.05 % below long-term average) and relatively warmer year (Table 1).

Model Description: Decision Support Systems for Agro-technology Transfer (DSSAT) is a process oriented dynamic crop simulation model. This model operates on a daily time step and simulates crop growth and development of different crops including sorghum (Jones *et al*. 2003) [6]. Model requires four main types of input data: weather, soil, crop and management. The daily weather data includes maximum and minimum temperature, rainfall and solar radiation, soil data includes texture, colour, slope, nitrogen and organic matter content across layers. Crop data includes cultivar specific genetic coefficients with information on development (phenology), biomass accumulation, grain yield and yield attributes, and management data includes, namely land preparation, planting dates, spacing, plant density, fertilization amounts and timing or other agricultural practices which were followed for the crop as per the recommendations of the university for NTZ.

Model calibration and validation: Calibration is a process of adjusting and/or optimizing model parameters, especially cultivar specific genetic coefficients, so that the model simulated outputs match well with observed data from the experimentation for a given cultivar before the model is validated and used for other application using those crop cultivars. In this project four *kharif* sorghum cultivars as listed above were screened across three dates of sowing. The genetic coefficients of these four cultivars within DSSAT-CERES Sorghum model were calibrated with data collected from *kharif* 2011 experiment. The genetic coefficients for the varieties used in the present simulation studies were optimized using Gencalc (Hunt *et al*. 1993) [5], a semi-automated program embedded within DSSAT to optimize genetic coefficients, followed by manual method. Whereas, the data collected from *kharif* 2012 experiment was used for evaluation of the model. The detail on optimized coefficients for each genotype and the description of each coefficient along with the results on performance of DSSAT-CERES-Sorghum model is presented and discussed in Sannagoudar *et al*. (2019) [13].

Results and Discussion

Weather and crop growth: Weather is a basic and fundamental factor to determine the plant growth. Any fluctuations in weather condition directly influences the crop growth and development, and finally reflect on the yield of crop. The management practices at times reduce adverse effect of temporal variability in weather, but in other cases it will have little effect on the year to year variability (Eghball *et al*. 1995) [3]. This is mainly a result of variable weather conditions prevailing in a particular agro-climatic situation. In this context, the weather conditions prevailed during experimental period would definitely have direct bearing on the potentiality of any crop in general and sorghum in particular. The actual rainfall received during *kharif* 2011 was above normal *i.e*., 17.52 per cent excess over long term average for *kharif* season (Jun-Sep). Whereas *kharif* 2012 was a rain deficit year *i.e*., 35.05 per cent less than the long term average for *kharif* season (Jun-Sep). With regard to temperature 2011 was cooler by 0.5 ˚C than the 2012 (Table 1).

Response of kharif sorghum cultivars to moisture regimes: Two consecutive years of experimentation *i.e., kharif* 2011 and *kharif* 2012, represented low moisture stress and high moisture stress, respectively. Therefore, as expected, model simulated higher grain yield, above ground biomass and fodder yield during 2011 as compared with 2012 across dates of sowing, and genotypes (Table 2 and 3, Figure1 and 2)

Among the tested cultivars, during *kharif* 2011, the per cent difference in simulated grain yield between non-stressed and stressed condition was highest with cultivar CSH-16 (29.68 %) followed by CSV-23 (23.81 %), CSH-23 (22.93 %) and CSV-17 (13.08 %). Whereas, during the year *kharif* 2012, the per cent yield difference between non-stressed and stressed condition was highest with CSV-17 (36.94 %) followed by CSH-16 (30.80 %), CSH-23 (29.68 %) and CSV-23 (25.03 %). This difference might be due to sensitivity of each genotype to moisture regime besides the variation in yield traits, which in turn are influenced by physiological processes and buildup of photosynthates. Crop yields depend not only on the accumulation of photosynthates during the crop growth and development, but also on its translocation in the desired storage organs. These intern, are influenced by the efficiency of metabolic processes within the plant (Humphreys 1997, Oveysi *et al*. 2010) [4, 10].

Averaged across three dates of sowing and four cultivars, the grain yield obtained in 2011 under no-stress was 6105 kg ha^{-1} and in stressed was 5016 kg ha^{-1}, a difference of 21.71 %. Whereas, in 2012 under no-stress 4756 kg $ha^{-1}$was recorded compared with 3710 kg ha^{-1}in stressed condition, and a difference of 28.19 %. However, the per cent yield difference between no-stress and stress condition was higher in 2012 (30.68 %) as compared to 2011 (22.38 %), which was mainly due to lower rainfall and higher temperature during 2012 which resulted in the reduction of grain yield (Soler *et al*. 2007, Yin *et al*. 2016) [14,16]. Similar simulated trend was observed with respect to above ground biomass and stover yield. The results are also in agreement with the findings of Sandeep *et al.* (2017) [11] who used CMIP model and showed strong positive correlation between sorghum yield and rainfall during *kharif* season and in contrast strong negative association with yield with crop ET and irrigation required during kharif season showed that sorghum has undergone moisture stress.

The yield difference between non-stressed and stressed across cultivars was less during 2011 (4.45, 9.28, 21.36 %) as compared to 2012 (22.06, 26.57, 42.67 %, respectively). Among the four cultivars across dates of sowing the per cent difference between stressed and non-stressed was higher in the year 2012 (33.64 %) as compared with 2011 (12.05 %).

Response of kharif sorghum cultivars to dates of sowing: Optimum sowing time is one of the important non-cash inputs for successful crop production in all crops. Very good growth of the crop is obtained only when the crop is sown at an appropriate time when weather elements favour plant growth.

Irrespective of cultivars, crop sown on 15th June showed less difference between stressed and non-stressed yields but delayed sowing increased this difference (6.46 and 22.77 % in the year 2011 and 2012, respectively) but delayed sowing increased this difference (19.35 and 22.94 % in the year 2011 and 2012, respectively, for 30th June and 41.31 and 46.14 % in the year 2011 and 2012, respectively for 15th July). Higher grain yield under early sown crop was mainly attributed to higher radiation use efficiency and higher synthesis of metabolites leading to higher total dry matter production at grain filling and maturity, and in turn higher grain yield (Liu *et al*. 2013, Karhale *et al*. 2014) [8,7]. Similar observation was reported by Buldak, *et al*. (2016) [1] from Rajasthan who observed that grain sorghum yield were higher under early sown crop i.e. June-30 as compared to late sowing (July-30).Similar trend was observed with respect to simulated fodder yield (Table 3) above ground biomass (Figure 2a and 2b).

Table 1: Mean monthly meteorological data for the experimental years (2011 and 2012) and mean of past 30 years (1985-2014) at MARS, UAS, Dharwad

Month	Rainfall (mm)			Tmax (˚C)			Tmin (˚C)			Solar Radiation (MJ/m²/day)		
	2011	2012	1985-2014	2011	2012	1985-2014	2011	2012	1985-2014	2011	2012	1985-2014
May	66.60	3.80	68.40	34.70	35.70	35.20	21.30	21.50	21.20	23.29	23.58	21.57
Jun.	194.00	43.40	109.70	27.50	30.20	29.60	21.30	21.20	21.10	17.96	18.21	17.64
Jul.	131.00	112.20	134.20	26.90	27.30	27.20	20.60	20.80	20.70	15.48	15.90	15.74
Aug.	124.20	90.00	105.20	26.70	27.20	26.80	20.70	20.50	20.40	15.85	16.38	15.67
Sept.	82.80	89.60	103.60	28.10	28.20	28.40	19.90	19.70	20.00	19.50	17.94	14.87
Total / Mean	532.00	335.20	452.70	27.30	28.22	28.00	20.62	20.55	20.55	17.19	17.10	15.98
Remarks*	+17.52 %	- 35.05%	--	-0.70	+ 0.22	--	+0.07	+0.00	--	+1.21	+1.12	--

* Values under remarks row in 2011 and 2012 columns for each meteorological parameter indicate change over long-term average (1985-2014) for the period from June-September only and May month is pre-sowing and pre-monsoon period hence not included.

Table 2: Simulated grain yield (kg/ha) of *kharif* sorghum genotypes as influenced by dates of sowing and moisture regimes

Treatments		Grain yield (kg/ha)									
		2011					2012				
		No stress	Stress	Difference over stress (%)	Difference over stress across DOS (%)		No stress	Stress	Difference over stress (%)	Difference over stress across DOS (%)	
CSV-17	D_1	3790	3739	1.36			3432	2723	26.04		
	D_2	3873	3561	8.76			3155	2458	28.36		
	D_3	3967	3072	29.13	D_1	6.46	2869	1834	56.43	D_1	22.77
	Mean	3877	3457	13.08			3152	2338	36.94		
CSV-23	D_1	6686	6304	6.06			6418	5338	20.23		
	D_2	6572	5397	21.77	D_2	19.35	4632	3866	19.81	D_2	22.94
	D_3	6649	4630	43.61			4584	3394	35.06		
Mean		6636	5444	23.81			5211	4199	25.03		
CSH-16	D_1	7517	6628	13.41			6959	5721	21.64		
	D_2	7471	5984	24.85			5423	4328	25.30		
	D_3	7377	4893	50.77	D_3	41.31	5077	3490	45.47	D_3	46.14
	Mean	7455	5835	29.68			5820	4513	30.80		
CSH-23	D_1	6485	6175	5.02			5652	4589	23.16		
	D_2	6390	5236	22.04			4569	3863	18.28		
	D_3	6484	4575	41.73			4298	2912	47.60		
Mean		6453	5329	22.93			4840	3788	29.68		
Grand mean		6105	5016	22.28			4756	3710	30.62		

D_1: June 15th, D_2: June 30th, D_3: July 15th

Table 3: Simulated fodder yield (kg/ha) of *kharif* sorghum genotypes as influenced by date of sowing and moisture regimes

Treatments		Fodder yield (kg/ha) at maturity									
		2011					2012				
		No stress	Stress	Difference over stress (%)	Difference over stress across DOS (%)		No stress	Stress	% Difference over stress	Difference over stress across DOS (%)	
CSV-17	D_1	5732	5719	0.23			4879	3768	29.49		
	D_2	5757	5679	1.37			5212	3583	45.46		
	D_3	5946	5723	3.90	D_1	2.82	4823	3586	34.50	D_1	21.37
Mean		5812	5707	1.83			4971	3646	36.48		
CSV-23	D_1	7640	7342	4.06			7348	6268	17.23		
	D_2	7324	7118	2.89			6866	4619	48.65		
	D_3	7696	7040	9.32			7019	5030	39.54		
Mean		7553	7167	5.42	D_2	3.59	7078	5306	35.14	D_2	47.00
CSH-16	D_1	8342	8072	3.34			7601	6392	18.91		
	D_2	7952	7407	7.36			7328	4987	46.94		
	D_3	8189	7315	11.95			7389	5285	39.81		
Mean		8161	7598	7.55			7439	5555	35.22		
CSH-23	D_1	7539	7275	3.63	D_3	8.61	6291	5249	19.85	D_3	40.93
	D_2	7288	7093	2.75			6828	4647	46.93		
	D_3	7464	6831	9.27			6809	4543	49.88		
Mean		7430	7066	5.22			6643	4813	38.89		
Grand mean		7239	6885	5.01			6533	4830	36.43		

D1: June 15th, D2: June 30th, D3: July 15th

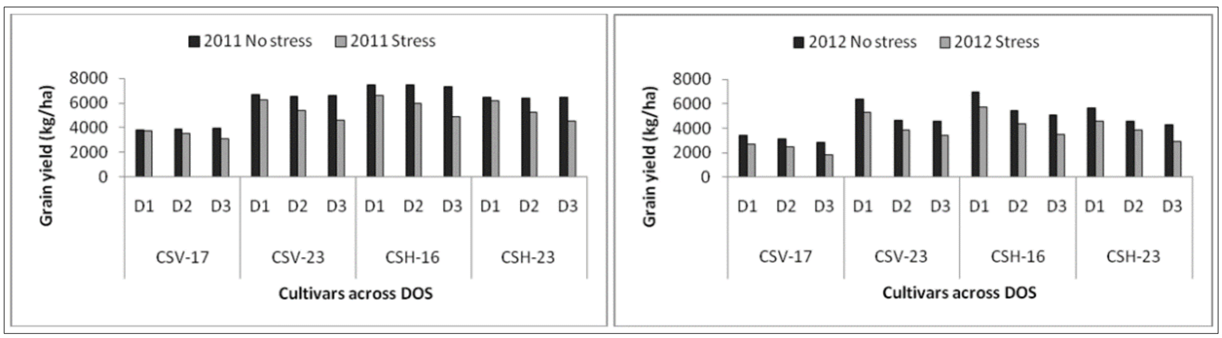

Fig 1a&1b: Simulated grain yield (kg/ha) of *kharif* sorghum genotypes as influenced by dates of sowing and moisture regimes

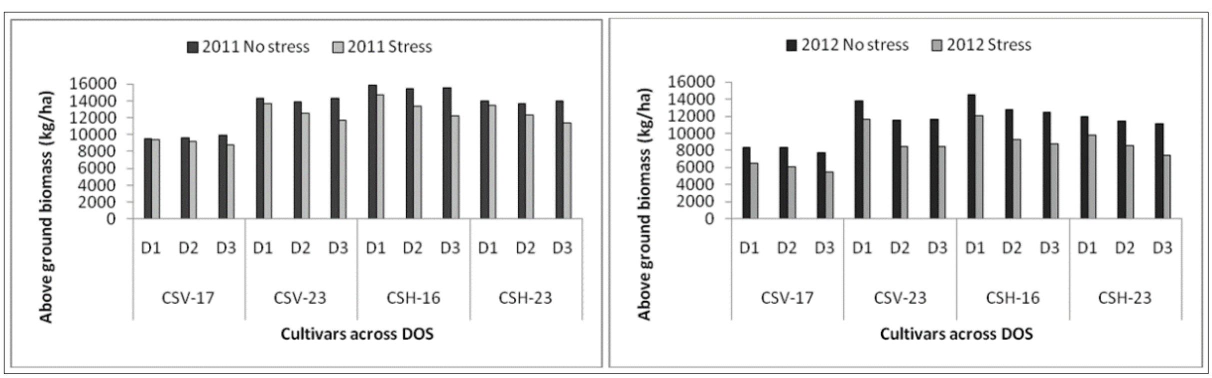

Fig 2a&2b: Simulated above ground biomass (kg/ha) of *kharif* sorghum genotypes as influenced by dates of sowing and moisture regimes

Conclusion

Results from this simulation study revealed that DSSAT-CERES Sorghum model, only after thorough calibration and evaluation using independent data sets for the chosen genotypes, can successfully be used to simulate growth and yield of *kharif* sorghum genotypes for various applications. This study in particular showed that variation in rainfall between years greatly affected *kharif* sorghum yield and during both the year's crop which experienced moisture stress, thus yield was lower in stressed (rainfed crop) than the yield in non-stressed condition (irrigated). This supports our hypothesis that recently released *kharif* sorghum genotypes in NTZ requires supplemental irrigation at critical stages to realize the potential yield. Among the different cultivars tested here CSH-16 performed well as compared to others across moisture regimes and dates of sowing. Among the dates of sowing, June 15 sown crop realized higher yield both under stressed and no-stressed condition as compared to later sown crop. This study revealed that *kharif* sorghum was found to be highly sensitive to variation in rainfall amount between year's vis-à-vis changes in soil moisture availability. Hence, supplemental irrigation is required during below normal or deficit years to prevent yield loss and realize potential yield of *kharif* sorghum in NTZ of Karnataka.

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