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Research Paper

Simulated Effect of Dry Spells at Critical Growth Stages on the Performance of *kharif* Sorghum Hybrids

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ABSTRACT

Potential impacts of climate change on grain sorghum (*Sorghum bicolar*) productivity were investigated using the CERES-sorghum model in Decision Support System for Agrotechnology Transfer (DSSAT) v4.7. The model was first calibrated for two sorghum hybrids (CSH-16 and CSH-23) for two consecutive years, 2011 and 2012, by Manjangouda *et al.* (2019) under the Northern Transitional Zone of Karnataka. In this study validated and calibrated DSSAT CERES model for both the hybrids was used to simulate the effect of dry spells – 2 weeks and 4 weeks before panicle initiation and end of grain filling stages across 3 dates of sowing (1st fortnight of June, 2nd fortnight of June and 1st fortnight of July) and model was run for the two consecutive years 2011 and 2012. Pooled data of two years, simulated outputs showed that irrespective of hybrids, date of sowing, and phase of the crop, withdrawal of rainfall for 4W resulted in a higher grain yield reduction (48.27 %) as compared to withdrawal of rainfall for only 2W (23.96 %). Among the two crop phases tested the crop phase before PI was found to be more sensitive to dry spells as the model simulated 38.90 and 71.46 Percent reduction in grain yield with 2W and 4W skipping of rainfall, respectively. At the same time, only 9.02 and 25.09 percent reduction in yield was observed with skipping of rainfall for 2 W and 4W prior to EGF. Similar trend was observed for top weight and root weight. We conclude that crop simulation models are applicable to assessing possible impacts of climate change on *Kharif* sorghum. This study concludes that exposure of crop to low moisture stress at peak vegetative phase, *i.e.*, 2W to 4W before PI, results in a higher reduction of the grain yield. Hence, if a dry spell occurs at this phase, supplemental irrigation should be provided to realize a higher grain yield.

HIGHLIGHTS

- Sorghum is a drought-tolerant crop that can be grown in both *Kharif* and *rabi* seasons of NTZ of Karnataka. The changing climate situations affect its potential yields.
- DSSAT CERES-sorghum model simulated the effect of dry spells – 2 weeks and 4 weeks before panicle initiation and end of grain filling stages.
- Model simulated 38.90 and 71.46 Percent reduction in grain yield with 2W and 4W skipping of rainfall, respectively. Whereas only 9.02 and 25.09 percent reduction in yield was observed with skipping of rainfall for 2 W and 4W prior to EGF.

Keywords: Sorghum, DSSAT (CERES), Moisture stress, Calibration, Validation and simulation

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth major cereal crop in India and is grown during both *kharif* and *rabi* seasons. Its major area is concentrated in the Deccan Plateau, Central, and Western India,

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apart from a few patches in Northern India. More than 90 % of the total area is rainfed (Sandeep *et al*. 2017). About 85 % of total production is concentrated in the semi-arid regions of Karnataka, Maharashtra, Telangana, and Andhra Pradesh (DACNET, 2016). 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 (Anon., 2016), 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*. But the deficit monsoon has become chronic after 2000, witnessing below-normal rains and drought years - 2002, 2004, 2009, 2014, 2015, 2016, 2017, and 2018.

In Northern Transition Zone climate is hot, dry, and sub-humid and the annual rainfall is >850 mm about 61 percent of the rainfall is received in the *kharif* season, which is about average rainfall of 430 mm, 130 mm in the pre-monsoon and 168 mm in the north east monsoon (Kajal, 2020). South West Monsoon (SWM; June-September) accounts for 70 % of the total annual rainfall of the Northern Interior Karnataka (NIK); hence the spatial and temporal variation in rainfall during this period greatly influences crop yield as NIK is much drier and warmer than the rest of the state. North interior Karnataka and the state's coastal region has witnessed a reduction in the amount of annual rainfall since 1960. In recent times the impacts of climate change have been observed in Karnataka in the form of natural calamities, rising sea levels, and changing weather. Changes in key climatic factors-especially rainfall-have been observed over Karnataka, according to an assessment by the Karnataka State Natural Disaster Monitoring Centre (KSNDMC).

While the amount of annual rainfall and the number of rainy days have increased in South Interior Karnataka (SIK) and malnad regions, there has been a reduction in the S-W monsoon in Northern Interior Karnataka (NIK) and coastal regions from 1960-1990 period to the 1991-2017 period (KSNDMC, 2020). The long-term average rainfall variability (CV in %) during SWM season in NIK is much higher (21%) than that of Karnataka state (15 %) and India (11 %) as a whole (Venkatesh *et al*. 2016). Therefore *kharif* crops, more often than not, do experience moisture stress due to inter-annual and inter-seasonal variability in rainfall, thus yielding less than potential levels.

Bold values are significant at (99 %) Confidence level

Decreased rainfall trends: the analysis of mean rainfall variations at state, regional, and district levels shows positive and negative shifts. The observed position change in southwest monsoon rainfall (mm) in Dharwad was minus 21 mm as compared to the state minus 6 mm. in the above table, also note mentioning that there was a marginal increase in pre-monsoon, southeast monsoon, and annual rainfall in the state, whereas Southwest monsoon showed a decreased trend.

Droughts in Karnataka: The occurrence of extreme weather events has increased in frequency and intensity across Karnataka in the last decade. Between 2001 and 2019, the state has experienced a drought of varying severity for 15 years. Some

Table 1: The district-regional and state level variations in the amount of Karnataka's rainfall: P1 (period 1) (1960-1990) and P2 (period 2) (1991-2017)

Sl. No.	Region	Southwest Monsoon Rainfall				Annual Rainfall			
		P1 (mm)	P2 (mm)	Change (mm)	Change (%)	P1 (mm)	P2 (mm)	Change (mm)	Change (%)
1	Dharwad	491	470	-21	-4	747	750	3	0
2	SIK	375	390	15	4	719	777	58	8
3	NIK	492	462	-30	-6	708	699	-9	-1
4	Malnad	1201	1254	53	4	**1548**	**1652**	104	7
5	Coastal	2872	2764	-108	-4	3250	3214	-36	-1
6	State	805	799	-6	-1	1102	1135	33	3

talukas have been drought affected consecutively for more than five years. In 2016 out of 176 *talukas* in the state, 139 were drought-affected in the *Kharif,* and 162 *talukas* were drought-affected in the *rabi* season. Similarly, in 2018, about 100 *talukas* were drought-affected in the *kharif* season and 156 *talukas* in the *rabi* season. A majority of districts in the NIK region once were subjected to severe drought.

Percent yield gap of, on an average 25 % was noticed between frontline demonstrations (FLD's) and state average yield (SAY) of sorghum. The main reason for declining in yield is the occurrence of long dry spells in one or the other stages of crop growth since sorghum is mainly grown in dry areas of the state. Hence simulation modeling stress study was conducted using DSSAT-CERES model. Crop models can also be used for crop yield forecasting with the potential to forecast production scenarios well before the harvest of the crop (Jones, 2003).

MATERIALS AND METHODS

The field experiment, from which the data for modeling was used, was conducted during *kharif* seasons of 2011 and 2012 under AICRP on Sorghum at MARS, Dharwad, Karnataka, located at 15° 26′ North latitude, 75⁰ 07′ East longitude, and at an altitude of 678 m above mean sea level (MSL), with the average annual rainfall from 1985-2014 was 722.80 mm, and rainfall during *kharif* 2011 and 2012 (June-September) was 532.00 and 335.20 mm, respectively, representing two different situations; 2011 was above-normal year, and 2012 was rain deficit and relatively warmer year. The experiment involved three dates of sowing (DOS) *viz.*, 15 June (D_1), 30 June (D_2) and 15 July (D_3), and two genotypes *viz.*, CSH-16 and CSH-23.

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 (Matthews *et al*. 2002). The 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, color, slope, nitrogen, and organic matter 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 soil 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 and scenarios: The calibrated and validated DSSAT-CERES-Sorghum model (Manjangouda *et al*. 2019) was used to simulate grain yield and above-ground biomass of hybrid sorghum. The daily weather files of 2011 and 2012 were used to create four dry spell scenarios by skipping rainfall for (turning into zero mm). The amount of rainfall withdrawn in respective scenarios is presented in Table 2.

(i) 2W (Two weeks) prior to PI (Panicle Initiation)
(ii) 4W (Four weeks) prior to PI
(iii) 2W prior to the EGF (End of grain filling)
(iv) 4W prior to EGF

The main rationale behind creating these above-mentioned stresses is to run each genotype for the observed weather of two years (2011 and 2012), which represents the annual variations expose the crop to stress at two critical growth stages, and quantify the percent yield reduction. This simulation study was taken up with the objective of identifying the most sensitive crop phase of *kharif* sorghum hybrids to moisture stress and to quantify the effect of time and extent of moisture stress on above and below-ground biomass of *kharif* sorghum. Simulated outputs of two years were averaged and presented here.

RESULTS

Simulated grain yield, tops weight and root weight of *kharif* sorghum hybrids to moisture stress scenarios (mean of 2011 and 2012 were presented here)

Among the two genotypes tested here, under the current rainfall situation across three different dates of sowing highest grain yield was simulated in CSH-16 (6923 kg/ha) as compared to CSH-23 (6622 kg/ha) (Table 3). Withdrawal of moisture in

Table 2: Amount of rainfall (mm) skipped in respective scenarios

Treatment		PI				EGF			
		2 W		4 W		2 W		4 W	
Variety	DOS	2011	2012	2011	2012	2011	2012	2011	2012
CSH-16	D_1	29.1	11.6	83.2	84.9	62.9	58.3	95.4	116.2
	D_2	75.4	123.9	104.2	135.5	40.9	28.5	88.4	86.8
	D_3	75.4	67.9	65.5	184.9	33.8	1.3	91.2	64.3
CSH-23	D_1	40.7	13.4	97.2	34.4	11.4	29	93.4	86.8
	D_2	64.4	131.3	98.8	144.6	64.9	1.3	65.3	87.4
	D_3	56.2	57.9	76	186.3	64.9	55.7	62.9	56.6

Table 3: Simulated grain yield (kg/ha) of *kharif* sorghum genotypes under different scenarios, across different dates of sowing (mean values of 2011 & 2012)

Genotypes	DOS	Grain yield (kg/ha)				
		2WPI	2WEGF	4WPI	4WEGF	OBSERVED
CSH-16	D_1	5915	6379	3244	5568	6923
	D_2	2648	5716	1785	4569	5754
	D_3	2367	4143	941	3796	4736
CSH-23	D_1	5641	5617	3028	4552	6622
	D_2	2367	5305	606	3836	5319
	D_3	2528	3742	830	3103	4577

the above-mentioned scenarios (Table 2) for two weeks to four weeks at two critical growth stages *i.e.* before panicle initiation (PI) and end of grain filling stage (EGF) has drastically reduced the grain yield under simulated conditions for both the genotypes, irrespective of sowing dates. Among two critical growth stages, panicle initiation was found to be more sensitive to low moisture stress for a more extended period of 4W and simulated in lowest grain yield as compared to observed (53.85 to 80.11% and 55.11 to 81.88 % reduction over observed in CSH-16 & CSH-23, respectively) across three dates of sowing (Fig. 1). Whereas, only 7.07 and 10.98 percent reduction in grain yield was observed irrespective of sowing windows with skipping of rainfall for 2W prior to EGF in CSH-16 and CSH-23, respectively. Among three different dates of sowing crop sown on 15th June (D1) performed better both under stressed and non-stressed situations and simulated in higher grain yields in both the genotypes as compared to D2 (30th June) and D3 (15th July).

Higher tops weight was simulated under normal rainfall conditions in CSH-16 at the first sowing window (D1) (16155 kg/ha) and the lowest in CSH-23 (12645 kg/ha) at the second sowing window (D2). Similarly, low moisture stress scenarios over two critical growth stages influenced the tops weight of sorghum genotypes under different sowing windows (Table. 4). Withdrawal of moisture for a longer period (4W) before panicle initiation (PI) proportionally reduced the tops weight of both the genotypes across all the sowing dates. Greater reduction of tops weight over observed was simulated in CSH-23 (75.71 %) and CSH-16 (74.62 %) in the third date of sowing (D3), when moisture was withdrawn for a longer period (4W) before panicle initiation (PI) stage followed by withdrawal of moisture for two weeks (2W) before panicle initiation stage (47.75 and 47.65 % in CSH-16 & CSH-23, respectively). Whereas only an 8.87 and 10.77 percent reduction in grain yield was observed irrespective of sowing windows with skipping of rainfall for 2W prior to EGF in CSH-16 and CSH-23, respectively (Fig. 2).

Likewise, genotypes, sowing windows, and low moisture stress also influenced root weight. Delayed sowing on 15th July (D3), both genotypes (CSH-16 & CSH-23) simulated higher root weight (1021 and 1020 kg/ha, respectively) under observed (Table 5). Withdrawal of moisture in above-mentioned scenarios proportionally reduced the root weight

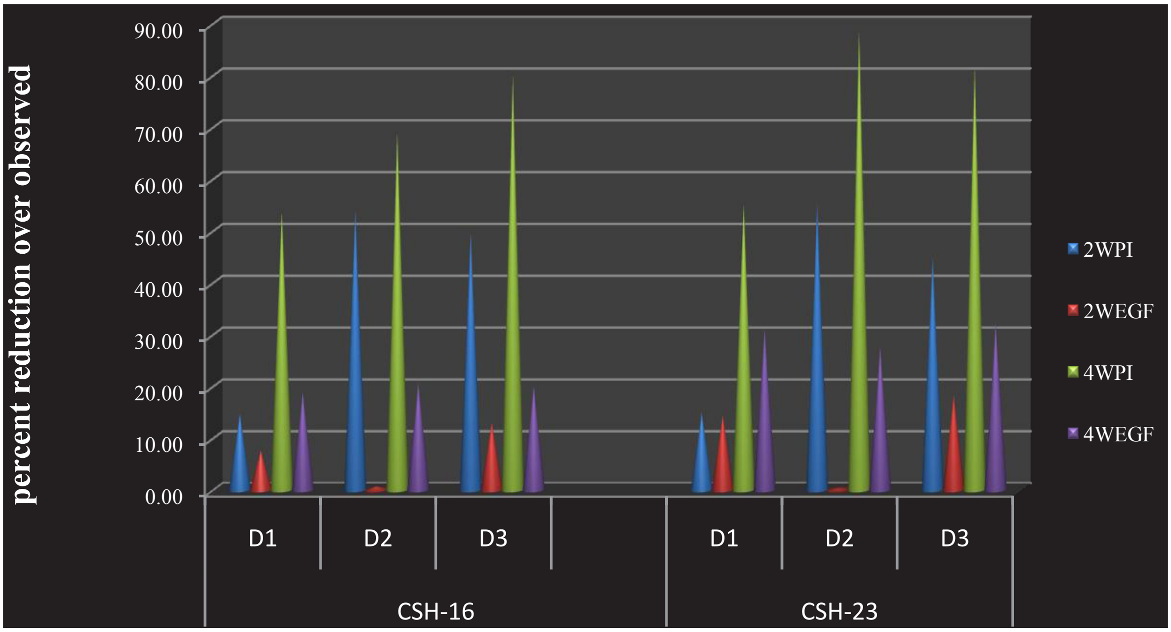

Fig. 1: Per cent yield reduction of *kharif* sorghum hybrids over observed

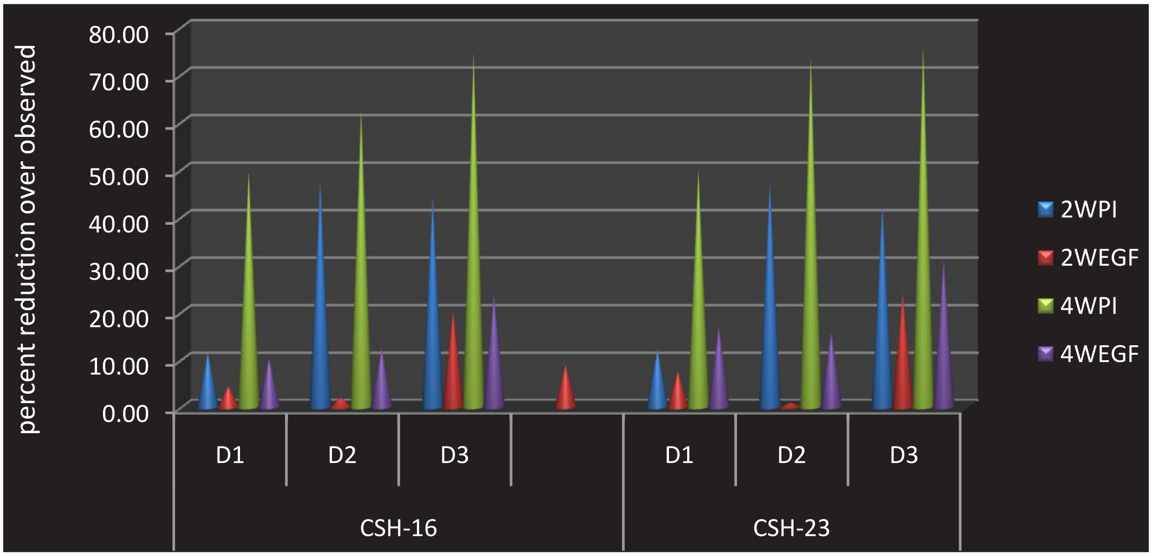

Fig. 2: Percent reduction of tops weight of *kharif* sorghum hybrids over observed

of all the genotypes across all the sowing dates. Both genotypes simulated higher root weight when sown on 15th June (D1) under low moisture stress situation. In contrast, exposure of crop to more extended dry spell (4W) before panicle initiation (PI) simulated in reduced root weight over observed (45.77 % and 48.03 % in CSH-16 and CSH-23, respectively) irrespective of sowing windows followed by 2W dry spells before PI (19.00 & 21.54 % in CSH-16 and CSH-23, respectively). Whereas only an 11.84 and 11.87 percent reduction in root weight was observed irrespective of sowing windows with skipping of rainfall for 2W prior to EGF in CSH-16 and CSH-23, respectively (Fig. 3).

DISCUSSION

Impact of climate change and variability on crops, the special and temporal variability of these impacts remain uncertain (Gebrekiros *et al.*, 2016). Rainfall is one of the most important climatic factors driving the rate of plant growth and development (Manjanagouda *et al.*, 2020). Better defining niches for strategic agricultural productivity improvements could help further improve the sustainability of

Table 4: Simulated tops weight (kg/ha) of *kharif* sorghum genotypes under different scenarios

Genotypes	DOS	Tops weight (kg/ha)				
		2WPI	2WEGF	4WPI	4WEGF	OBSERVED
CSH-16	D_1	14315	15412	8356	14398	16155
	D_2	7048	13312	5067	11899	13583
	D_3	7282	10303	3273	9869	13168
CSH-23	D_1	13438	14059	7869	12729	15315
	D_2	6558	12536	3338	10639	12645
	D_3	7273	9382	2998	8584	12768

Table 5: Simulated root weight (kg/ha) of *kharif* sorghum genotypes under different scenarios

Genotypes	DOS	Root weight (kg/ha)				
		2WPI	2WEGF	4WPI	4WEGF	OBSERVED
CSH-16	D1	836	854	379	837	885
	D2	620	818	496	798	870
	D3	716	703	517	689	1021
CSH-23	D1	774	797	497	793	828
	D2	608	796	450	753	827
	D3	633	670	384	619	1020

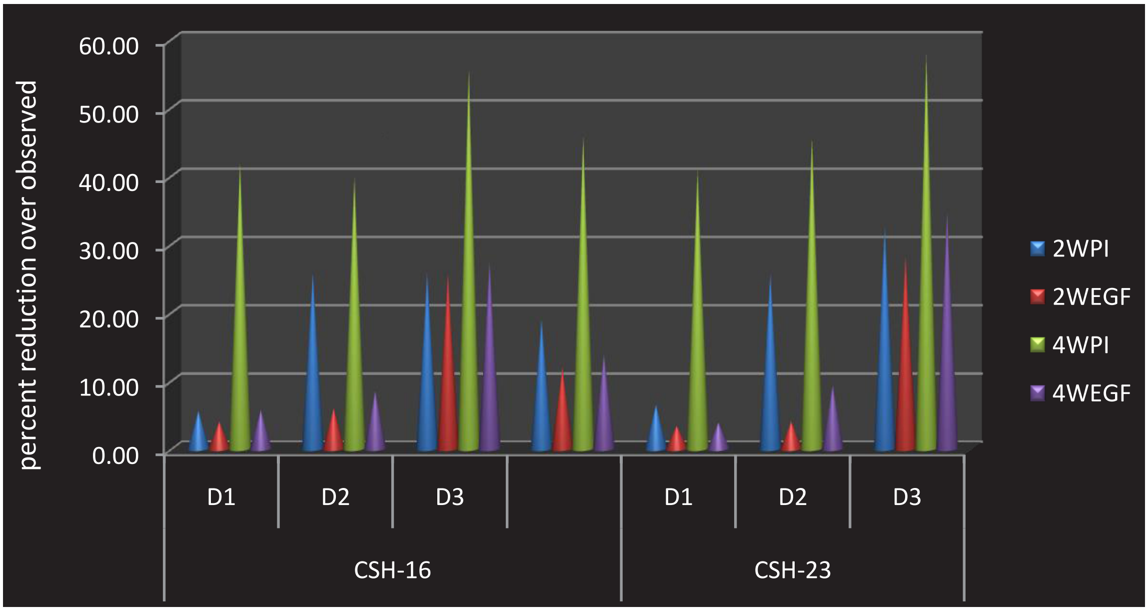

Fig. 3: Per cent reduction of root weight of *kharif* sorghum hybrids over observed

food production in water-limited environments (Akinseye *et al.* 2017). More dry spells are expected in the coming decades and will impact both crop growth and productivity (Cooper *et al.* 2009; Esterling, 1996). Simulation models have proven to be excellent tools for exploring the potential of certain crops under changed climatic situations (Whitbread *et al.* 2010). DSSAT-CERESS sorghum models sensitivity analysis outputs on grain yield and top weight (above ground biomass) showed a drastic reduction in grain yield and top weight for all the dry spell scenarios irrespective of stage and dates of sowing. Across genotypes, irrespective of sowing windows, dry spells have reduced the grain yield and top weight up to >80 percent. Among the two genotypes tested, the model simulated CSH-16 performed the best yielder under all the four low moisture stress scenarios and across all sowing windows as compared to CSH-23. The reduction in yield under low moisture stress is mainly attributed to a reduction in total crop duration (Marine *et al.* 2015) and also due to reduced source development, assimilation of photosynthesis, and further translocation towards the sink, which might be due to reduced leaf area and leaf number. The *kharif* sorghum in NTZ is usually sown in June with the onset of southwest monsoon rains and is usually harvested by the end of September. This period receives some 80 percent of total annual rainfall. Therefore, a percent reduction in yield of *kharif* sorghum genotypes was observed in this study for each dry spell at both crop phases (PI & EGF). Bhoomiraj *et al.* (2012) used the Infocrop model and simulated the effect of future climate change scenarios on *kharif* sorghum yields at different locations across India (Akola, Anantapur, Coimbatore, & Bijapur). They found that yield of CSH-16 will increase little at Gwalior (0.1 %) until 2020 and after that will reduce variations in yield reduction of sorghum under projected climate change scenarios at different locations of India was primarily attributed to currently prevailing temperature ranges and rainfall. However, the highest reduction in yield would be by 2080 and was simulated for Coimbatore, where 2.6oC increase in temperature was projected for 2080 AD as this location received low rainfall during *kharif* season. Increased yields at Gwalior and Kota until 2020 due to the projected little increase in rainfall.

The higher grain yield and tops weight under early sown crop (15th June) might be attributed to relatively longer crop duration and increased access to soil moisture, which may have helped in the higher synthesis of metabolites leading to higher total dry matter production and assimilation at grain filling and maturity stage, thus higher grain yield and tops weight was produced (Karhale *et al*. 2014; Saini *et al*. 2018). Crop growth phase prior to PI was found to be more sensitive to low moisture stress irrespective of genotypes and sowing windows, as this phase of the crop will be at the vegetative phase, and leaf expansion and daily biomass accumulation, in particular, will be severely inhibited by low moisture stress. Exposure of crop to more extended dry spell (4W) leads to higher yield loss (>80 %), as the crop subjected to severe water stress results in a significant drop in their maximum photosynthetic rates, thus assimilation and its partitioning will be reduced.

Model simulated reduced root weight when stress was created for longer period its mainly attributed to the imbalanced situation between source-sink relationship under limited water supplies. Some results also showed that root growth of sorghum under soil drying could be modeled by five simple relationships, the production of new root length as a function of above-ground crop growth; the rate of descent of the root system; the distribution of the new root length with depth, the limitation to root proliferation is the primary function of soil water content and also suggested that there is no significant chemical and physical constraints that limit the proliferation of roots under well-watered conditions. The root length ratio to above-ground biomass was relatively stable, but it will vary more under a broader range of stress levels (Robertson *et al*. 1993). Partitioning of total growth between root and shoot depends on the shoot water status (Huck and Hillel, 1953). This is the reason we achieved less root weight under low moisture stress situations when crops expose to a longer period of dry spells.

Model simulated results showed that among the *kharif* sorghum genotypes tested, CSH-16 gave higher and stable grain yields even under low moisture stressed situations and dates of sowing as compared to CSH-23. Among the dates of sowing, in all the dry spell scenarios, early sowing (15th June) recorded a higher grain yield as compared to late sowing (30th June and 15th July). Irrespective of genotypes and sowing windows PI was found to be the more sensitive stage for low moisture stress, a longer period of moisture stress resulted in higher yield reduction.

CONCLUSION

With climate change, as in other parts of Southern India, the Northern Transitional Zone of Karnataka would also witness longer dry spells during *Kharif* season in the coming decades. Understanding and quantifying crop responses to projected changes in temperature is an essential step in developing adaptation strategies and policy decisions to cope with it to maintain higher productivity despite climate change. This study concludes that exposure of *kharif* sorghum to low moisture stress at peak vegetative phase, *i.e.*, prior to PI and for a longer interval of time (4W) results in a higher reduction in grain yield. Hence. If the dry spell is forecasted at this crop growth phase, supplemental irrigation should be provided to realize a higher grain yield.

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