Original Research Article

Influences of changes in Rainfall and Solar Radiation on performance of *Kharif* Sorghum

ABSTRACT

Kharif sorghum is an important crop of the northern transition zone (NTZ) of Karnataka. Historically this zone was characterized by the assured and uniform distribution of rainfall during the southwest monsoon. The last decade has witnessed increased erraticity in the onset, progress and distribution of rainfall, but days without rain also remain cloudy for weeks during *Kharif* season, thus lower the crop canopy, which affects the yield, interrupts solar radiation. Solar radiation, rainfall are the two important climatic factors affecting crop performance, but it is logistically difficult, and resource demanding to artificially create study-growing environment under field conditions. Alternately, Crop Simulation Models can be effectively used for such studies by creating customized weather scenarios within the model. Four rainfall scenarios (±10 and ±20 % over observed) and four solar radiation scenarios (±10 and ±20 % over observed) were created by using 32 years' observed weather data (1985-2016) within the calibrated and validated DSSAT-CERES-Sorghum model (Manjanagouda *et al.*, 2019).

Simulations were run across all the above scenarios for 32 years' seasonal analysis with the best four *kharif* sorghum cultivars sown across three dates of sowing under the standard package of practices followed for NTZ. Model simulated annual outputs for grain yield over 32 years were averaged and presented. The model simulated results revealed that for NTZ changes in solar radiation was found to have more effect on yield than rainfall. Any reduction in solar radiation over observed drastically reduces the yield. Across cultivars and dates of sowing under observed weather (1985-2016), on average, 1720 kg ha^{-1} yield was simulated. When solar radiation was reduced by 10 % across rainfall scenarios the average yield was reduced to 1424 kg ha^{-1} which further reduced to 670 kg ha^{-1} (61% reduction) when solar radiation was reduced by 20 %. In contrast, when solar radiation was increased by 10 % and 20 %, the model simulated 2967 kg ha^{-1} and 3181 kg ha^{-1} yield, respectively which is 42 and 46 % more over the yield of observed weather. This study showed that for NTZ of Karnataka during *the Kharif* season increased cloudy period will have a more adverse effect on yield than changes to rainfall.

Keywords: DSSAT-CERES model, rainfall, seasonal analysis, solar radiation, sorghum

Introduction

Agriculture is climate dependent and vulnerable to climate change. It is a need of the hour to prepare adaptation measures against climate change. Proper counter measures drawn based on scientific diagnosis and assessment of the impacts of climate change on agriculture are essential in establishing the vision and administrative policies of future agriculture. This will also provide valuable information for establishing mid to long-term agricultural development plans (Cenacchi *et al.* 2016).

The crop growth models are helpful to assess the impact of climate change on the stability of crop production under different management options (Hoogenboom *et al*., 1995). Crop growth simulation models provide an effective and efficient means to quantify the effect of climate as well as management practices on soil, crop growth, productivity and sustainability of agriculture production.

However, the extent of the impact of climate change on crop varies from region to region, crop to crop and from one production system to another, which includes different genotypes, input use the pattern or soil type and its fertility level and water holding capacity. Hence, climate impact assessment studies are required at the zone or local level as well. Hence, this modeling work was taken up for the Northern Transitional Zone (NTZ) of Karnataka state, India to quantify the impact of changes in Rainfall and Solar Radiation on *kharif* sorghum crop using already calibrated and validated DSSAT–CERES sorghum model. (Manjanagouda *et al.*, 2019).

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the important nutritional cereal crops and the major staple food and fodder crop of millions of people in semi-arid tropics. It is known as the ‘King of millets’ and extensively cultivated in Africa, China, USA, Mexico and India. Sorghum ranks fourth among the world’s most important cereal crops after wheat, rice and maize. In India, it is cultivated in *kharif, rabi* and summer seasons. About 85 per cent of total production is concentrated in Maharashtra, Karnataka and Andhra Pradesh. Over the year’s area, production and productivity has decreased due to the introduction of cash crops, crops suited for mechanized production as well as changing food habits. Since sorghum is extensively cultivated as a rainfed crop, its productivity is largely influenced by climatic factors (Srivastava *et al*. 2010). Yield is affected by growing–season solar radiation, rainfall amount and its distribution, soil water content at planting, plant-available water during its growing period along with crop management practices (Assefa *et al*. 2010).

Materials and methods

Model calibration and evaluation

Four *kharif* sorghum genotypes *viz*, CSV-17, CSV-23, CSH-16 and CSH-23 were screened in a field experiment across three dates of sowing viz., 15th June, 30th June and 15th July for two seasons (2011 and 2012) under All India Coordinate Research Project (AICRP) on Sorghum at University of Agricultural Sciences, Dharwad, India located at 15° 26′ N latitude, 75° 07′ E longitude and an altitude of 678 m above mean sea level. This station is located in the Northern Transition Zone (Zone-8) of agro-climatic zones of Karnataka State of India that lies between high rainfall receiving Western Hilly Zone (Zone-9) and very low rainfall receiving Northern Dry Zone (Zone-3). The average annual rainfall of the experimental location for 1985–2014 was 521.10 mm (Table 1). Within the calibrated and validated DSSAT-CERES-Sorghum model (Manjanagouda *et al.,* 2019). for four genotypes were used in this modeling study to quantify the effect of changes in rainfall and solar radiation on *kharif* sorghum performance using seasonal analysis tool within DSSAT ensemble.

Table 1. Calibrated genotypic coefficients for four kharif sorghum cultivars

Parameters	CSV-17	CSV-23	CSH-16	CSH-23

P1	220.0	340.0	335.0	300.0
P2	85.0	70.0	80.0	90.0
P2O	12.50	12.50	12.50	12.50
P2R	43.70	85.0	90.0	90.0
PANTH	617.50	570.5	580.5	580.5
P3	130.50	142.5	135.5	140.5
P4	70.50	81.5	95.0	81.5
P5	540.0	590.0	650.0	570.0
PHINT	49.00	49.0	49.0	49.0
G1	10.00	5.0	5.0	5.0
G2	4.5	6.0	6.0	6.0

Table 2. Description of genetic coefficients of kharif sorghum cultivars

Parameters	Description
P1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in °C days above base temperature)
P2	Thermal time from the end of the juvenile stage to heading under short days (expressed in °C days above base temperature)
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 heading (expressed in °C days) is delayed for each hour increase in photoperiod above P2O
PANTH	Thermal time from the end of heading to fertilization (expressed in °C days above base temperature)
P3	Thermal time from to end of flag leaf expansion to fertilization (expressed in °C days above base temperature)
P4	Thermal time from fertilization to beginning of grain filling (expressed in °C days above base temperature)
P5	Thermal time from beginning of grain filling to physiological maturity (degree days above base temperature)
PHINT	Phylochron interval; the interval in thermal time between successive leaf tip appearances (expressed in °C days)
G1	Scaler for relative leaf size
G2	Scaler for partitioning of assimilates to the head

Seasonal analysis

Seasonal analysis tool within the DSSAT ensemble was used to test the response of four *kharif* sorghum genotypes popular in NTZ (as listed in Table 1) across eight combination scenarios, four rainfall scenarios (±10 and ±20 % over observed) and four solar radiation scenarios (±10 and ±20 % over observed) were created by using 32 years observed weather data (1985-2016). The main rationale behind using 32 years of baseline weather (1985–2016) was to run each genotype for recent past 32 years' observed weather which represents natural inter-annual and intra-annual variation, and expose the crop to the natural variability of weather representing below normal, above-normal and normal years of weather (in this case solar radiation and rainfall), as well as extremes if any experienced during simulation runs during these 32 years.

Table 3: Rainfall and solar radiation scenarios created for seasonal analysis using 32 years historical weather data (1985-2016)

Scenarios	**Remarks**
Control	Solar radiation and rainfall no change, and is the current scenario (*i.e.*, Observed weather for the period 1985-2016)
RF (10 % +) & SARD (10 % -)	Increase in rainfall by 10 % and reduction in solar radiation by 10 % for 1985-2016 period
RF (10 % +) & SARD (20 % -)	Increase in rainfall by 10 % and reduction in solar radiation by 20 % for 1985-2016 period
RF (20 % +) & SARD (10 % -)	Increase in rainfall by 20 % and reduction in solar radiation by 10 % for 1985-2016 period
RF (20 % +) & SARD (20 % -)	Increase in rainfall by 20 % and reduction in solar radiation by 20 % for 1985-2016 period
RF (10% -) & SARD (10 % +)	Decrease in rainfall by 10 % and increase in solar radiation by 10 % for 1985-2016 period
RF (10% -) & SARD (20 % +)	Decrease in rainfall by 10 % and increase in solar radiation by 20 % for 1985-2016 period
RF (20% -) & SARD (10 % +)	Decrease in rainfall by 20 % and increase in solar radiation by 10 % for 1985-2016 period
RF (20% -) & SARD (20 % +)	Decrease in rainfall by 20 % and increase in solar radiation by 20 % for 1985-2016 period

* RF – Rainfall and SARD – Solar radiation.

Results and Discussion

Climate is the most important dominating factor influencing the suitability and yield potential of a crop for a given location. That is why studies showed that more than 50 per cent of the variation in crop yield is determined by climatic factors (Eghball *et al.*, 1995). The most important climatic factors that influence growth, development and yield of crops are solar radiation and rainfall. Photosynthesis is mainly driven by the availability of solar radiation; hence, crop growth is affected with changes in solar radiation during crop growing season, whereas reduced rainfall creates moisture stress and affects physiological processes ultimately affecting yield.

Effect of variation in solar radiation at constant rainfall on yield

When rainfall was increased by 10 %, at 10 % reduction in solar radiation model simulated 1518 kg ha^{-1} yield, which further reduced to 785.4 kg ha^{-1} (48.2 % reduction) when solar radiation was reduced by 20 %. In contrast, when rainfall was increased by 20 %, at 10 % reduction in solar radiation model simulated 1329 kg ha^{-1} yield, which further reduced to 556.4 kg ha^{-1} (58.2 % reduction) when, solar radiation was reduced by 20 %. Here it can be observed that increase in rainfall amount has not contributed much to yield variation but reduction in solar radiation has affected the yield losses very much severally.

When rainfall was reduced by 10 %, at 10 % increase in solar radiation model simulated 3094.7 kg ha^{-1} yield, which further increased to 3372.4 kg ha^{-1} (8.9 % increase) when solar radiation was increased by 20 %. Whereas, when rainfall was reduced by 20 %, at 10 % increase in solar radiation model simulated 2838.9 kg ha^{-1} yield, which further increased to 2998.8 kg ha^{-1} (5.4 % increase) when solar radiation was reduced by 20 %. Here it can be seen that decrease in rainfall does not affect much to reduction in yield levels as compared to solar radiation.

Effect of variation in rainfall at constant solar radiation on yield

When solar radiation was increased by 10 %, at 10 % reduction in rainfall model simulated 3094 kg ha^{-1} yield, which further reduced to 2838.9 kg ha^{-1} (8.2 % reduction) when solar radiation was reduced by 20 %. In contrast, when solar radiation was increased by 20 %, at 10 % reduction in rainfall model simulated 3372.9 kg ha^{-1} yield, which further reduced to 2992.8 kg ha^{-1} (11.2 % reduction) when rainfall was reduced by 20 %.

When solar radiation was reduced by 10 %, at 10 % increase in rainfall model simulated 1158 kg ha^{-1} yield, which further increased to 1329 kg ha^{-1} (14.7 % increase) when rainfall was increased by 20 %. In contrast, when solar radiation was reduced by 20 %, at 10 % increase in rainfall model simulated 785.4 kg ha^{-1} yield, which further reduced to 554.4 kg ha^{-1} (29.4 % reduction) when rainfall was reduced by 20 %.

Effect of variation in solar radiation at constant rainfall on dry matter production

When rainfall was increased by 10 %, at 10 % reduction in solar radiation model simulated 3466.0 kg ha^{-1} yield, which further reduced to 1878.4 kg ha^{-1} (48.2 % reduction) when solar radiation was reduced by 20 %. In contrast, when rainfall was increased by 20 %, at 10 % reduction in solar radiation model simulated 3089.9 kg ha^{-1} yield, which further reduced to 1418.2 kg ha^{-1} (58.2 % reduction) when, solar radiation was reduced by 20 %.

When rainfall was reduced by 10 %, at 10 % increase in solar radiation model simulated 7338.3 kg ha^{-1} yield, which further increased to 8301.6 kg ha^{-1} (8.9 % increase) when solar radiation was increased by 20 %. In contrast, when rainfall was reduced by 20 %, at 10 % increase in solar radiation model simulated 6916.6 kg ha^{-1} yield, which further increased to 4163.6 kg ha^{-1} (5.4 % increase) when solar radiation was reduced by 20 %.

Effect of variation in rainfall at constant solar radiation on dry matter production

When solar radiation was increased by 10 %, at 10 % reduction in rainfall model simulated 7338.3 kg ha^{-1} yield, which further reduced to 6916.6 kg ha^{-1} (8.2 % reduction) when solar radiation was reduced by 20 %. In contrast, when solar radiation was increased by 20 %, at

10 % reduction in rainfall model simulated 8301.6 kg ha^{-1} yield, which further reduced to 4163.6 kg ha^{-1} (11.2 % reduction) when rainfall was reduced by 20 %.

When solar radiation was reduced by 10 %, at 10 % increase in rainfall model simulated 3466.0 kg ha^{-1} yield, which further reduced to 3089 kg ha^{-1} (14.7 % increase) when rainfall was increased by 20 %. In contrast, when solar radiation was reduced by 20 %, at 10 % increase in rainfall model simulated 1878.4 kg ha^{-1} yield, which further reduced to 1418.2 kg ha^{-1} (29.4 % reduction) when rainfall was increased by 20 %.

Performance of sorghum cultivars

Among all the cultivars CSH-16, recorded 2606.4 kg ha^{-1} grain yield and 6096.9 kg ha^{-1} dry matter production across the scenarios. Next better cultivars were CSV-23 (2270.7 kg ha^{-1} grain yield and 5563.5 kg ha^{-1} dry matter production) and CSH-23 (2139.3 kg ha^{-1} grain yield and 5153.1 kg ha^{-1} dry matter production). CSV-17 recorded lower grain yield 1227.1 kg ha^{-1} and 3329.1 kg ha^{-1} dry matter production.

Effect of dates of sowing

Simulation results across all the climate scenarios reviled that, crop sown on 15th June recorded 5198.1 kg ha^{-1} dry matter production and 2030.5 kg ha^{-1} grain yield. Meanwhile crop sown on 30th June recorded higher grain yield of 2394.6 kg ha^{-1} and 4949.8 kg ha^{-1} dry matter production. Late sowing on 15th July recorded lower grain yield (1961.4 kg ha^{-1}) and dry matter production (4795.5 kg ha^{-1}). Here early sown crop though recoded higher dry matter production it failed to convert to grain yield due to variation of climate.

Conclusion

The DSSAT 4.6 model based seasonal analysis study showed that sorghum crop was found to be more sensitive to changes in solar radiation than rainfall amount any reduction in solar radiation over observed drastically reduces the yield. When solar radiation was reduced by 10 % across rainfall scenarios the average yield was reduced to 1424 kg ha^{-1} which further reduced to 670 kg ha^{-1} (61% reduction) when solar radiation was reduced by 20 %. In contrast when solar radiation was increased by 10 % and 20 %, the model simulated 2967 kg/ha and 3181 kg/ha yield, respectively which is 42 and 46 % more over the yield of observed weather. This study showed that for NTZ of Karnataka during *Kharif* season increased cloudy period would have a more adverse effect on yield than changes to rainfall. Among the cultivars in study, CSH-16 performed better over all the cultivars. Sowing the crop on 30th June found to be optimum across all the climate scenarios

References

Assefa, Y., Staggenborg, S. A. and Prasad, V. P. V. (2010). Grain Sorghum Water Requirement and Responses to Drought Stress: A Review. *Cm.,* doi: 10.1094/CM-2010-1109-01-RV.

Cenacchi, N., Lin, Y., Sulser, T.B., Islam, S., Mason-D'Croz, D., Kim, C. G. and Wiebe, K.D. (2016). Climate change, agriculture, and adaptation in the Republic of Korea to 2050: an integrated assessment,. International Food Policy Research Institute: 1586.

Eghball, B., Power, J.F., Binford, G.D., Baltensperger, D.D. and Anderson, F.N. (1995). Maize temporal yield variability under long-term manure and fertilizer application: fractal analysis. *Soil Sci. Society of Am. J.* 59(5): 1360-1364.

Hoogenboom, G., Tsuji, G.Y., Jones, J.W., Singh, U., Godwin, D.C., Pickering, N.B. and Curry, R.B. (1995). Decision support system to study climate change impacts on crop production. ASA Spec. Publ. No. 59. *Am. Soc. Agron, Madison,* WI; 51–75.

Manjanagouda, S.S, Patil, R.H. and Rajanna, G.A. (2019). Calibration and evaluation of DSSAT–CERES model for *kharif* sorghum genotypes. *J. Exp. Agric. Int.* 30(3):1–8.

Srivastava, A., Naresh Kumar, S. and Aggarwal, P.K. (2010). Assessment on vulnerability of sorghum to climate change in India. *Agric. Ecosyst. Environ.*, 138:160–169.

Table 4: Grain yield of sorghum across the climate scenarios

Climate scenario	**Yield (Kg ha^{-1})**				
	Cultivar/ DOS	**CSV 17**	**CSV23**	**CSH16**	**CSH23**
RF (10 % +) & SARD (10 %-)	D1	685.4	865.5	2394.7	1643.1
	D2	586.3	2072.6	1664.28	1535.8
	D3	786.1	2047.6	2124.6	1809.9
	Mean	**685.9**	**1661.9**	**2061.2**	**1662.9**
RF (10 % +) & SARD (20 %-)	D1	250	1091.7	1433.3	918.5
	D2	117.06	696.2	1113.6	671.8
	D3	279.1	1171.5	1076.1	605.3
	Mean	**215.4**	**986.5**	**1207.7**	**731.9**
RF (20 % +) & SARD (10 %-)	D1	749.56	1701.2	1862.8	1567.8
	D2	419	1570.2	1537	1243.5
	D3	480.1	1746.8	1627.3	1453.2
	Mean	**549.6**	**1672.7**	**1675.7**	**1421.5**
RF (20 % +) & SARD (20 %-)	D1	145.8	618.8	864.1	743.4
	D2	149.7	556.8	846.3	568.5
	D3	161.3	402.5	903.1	704.1
	Mean	**152.3**	**526.0**	**871.2**	**672.0**
RF (10% -) & SARD (10 % +)	D1	1912.1	3464.1	4299.5	2944.8
	D2	1851.5	3578.8	3787.4	3598.9
	D3	1872.9	3055.8	3823	2949.9
	Mean	**1878.8**	**3366.2**	**3970.0**	**3164.5**
RF (10% -) & SARD (20 % +)	D1	2293.3	3847.8	4357.1	3407.8
	D2	2042.5	3886.2	4119.8	3695.7
	D3	2248.1	3328.4	4038.1	3203.8
	Mean	**2194.6**	**3687.5**	**4171.7**	**3435.8**
RF (20% -) & SARD (10 % +)	D1	1792.7	3268.9	3817.6	3068.7
	D2	1842.4	3365.3	3270	3359.7
	D3	1624.1	2647.2	3373.3	2636.3
	Mean	**1753.1**	**3093.8**	**3487.0**	**3021.6**
RF (20% -) & SARD (20 % +)	D1	1729.8	3417.3	3510.6	3086.7
	D2	3597.2	3423.8	3438.8	5898.6
	D3	1836.1	2673.4	3272.4	2806.5
	Mean	**2387.7**	**3171.5**	**3407.3**	**3004.6**
Normal	D1	825.2	1961.5	2493.1	1878.1
	D2	747.4	1869.5	2191.5	1716.1
	D3	664.9	2066.8	2188.8	1999.3
	Mean	**745.8**	**1965.9**	**2291.1**	**1864.5**

Table 5: Dry matter production of sorghum across the climate scenarios

Climate scenario	**Dry matter production (Kg ha^{-1})**				
	Cultivar/ DOS	**CSV 17**	**CSV23**	**CSH16**	**CSH23**
RF (10 % +) & SARD (10 %-)	D1	1838.5	1861.8	5247	3695.4
	D2	1616.9	4581.9	3658	3447.4
	D3	2153.5	4667.9	4640.1	4183.8
	Mean	**1869.6**	**3703.9**	**4515**	**3775.5**
RF (10 % +) & SARD (20 %-)	D1	784.21	2480.4	3169.7	2106.1
	D2	587.2	1460.6	2576.4	1702.3
	D3	936.4	2741.4	2451.1	1545.1
	Mean	**769.3**	**2227.5**	**2732.4**	**1784.5**
RF (20 % +) & SARD (10 %-)	D1	2073.3	3793.4	4092.7	3555.1
	D2	1202.1	3558.1	3431.9	2862.9
	D3	1404.7	4009	3739.8	3356.2
	Mean	**1560**	**3786.8**	**3754.8**	**3258.1**
RF (20 % +) & SARD (20 %-)	D1	518.5	1498.2	2003.4	1803.3
	D2	551.1	1440.8	1989.8	1455.3
	D3	592.5	1181.8	2172.7	1811.1
	Mean	**554**	**1373.6**	**2055.3**	**1689.9**
RF (10% -) & SARD (10 % +)	D1	5228.7	8187.4	10064.8	6991.1
	D2	5081.9	8072.1	8498.1	8081.1
	D3	5026.1	7176.5	8690.9	6960.3
	Mean	**5112.2**	**7812**	**9084.6**	**7344.2**
RF (10% -) & SARD (20 % +)	D1	6478.6	9326.1	10733.1	8386.5
	D2	5933.6	9008.4	9494.8	8525.6
	D3	6224.9	8054.2	9563.3	7889.5
	Mean	**6212.4**	**8796.2**	**9930.4**	**8267.2**
RF (20% -) & SARD (10 % +)	D1	5129.7	7769.6	9223.8	7410.1
	D2	5199.4	7688.1	7725	7760.6
	D3	4563.1	6417.9	7782.2	6329.7
	Mean	**4964.1**	**7291.9**	**8243.7**	**7166.8**
RF (20% -) & SARD (20 % +)	D1	5574.3	8442.9	8997.4	7873.5
	D2	5898.6	8504.9	8463.5	8337.2
	D3	5301.8	6800.6	7916.5	7172.6
	Mean	**5591.6**	**7916.1**	**8459.1**	**7794.4**
Normal	D1	2453.2	4799.7	5782.5	4581
	D2	2123	4498.3	5092.2	4040
	D3	1938.7	4957	4988.2	4709.6
	Mean	**2171.6**	**4751.6**	**5287.6**	**4443.5**

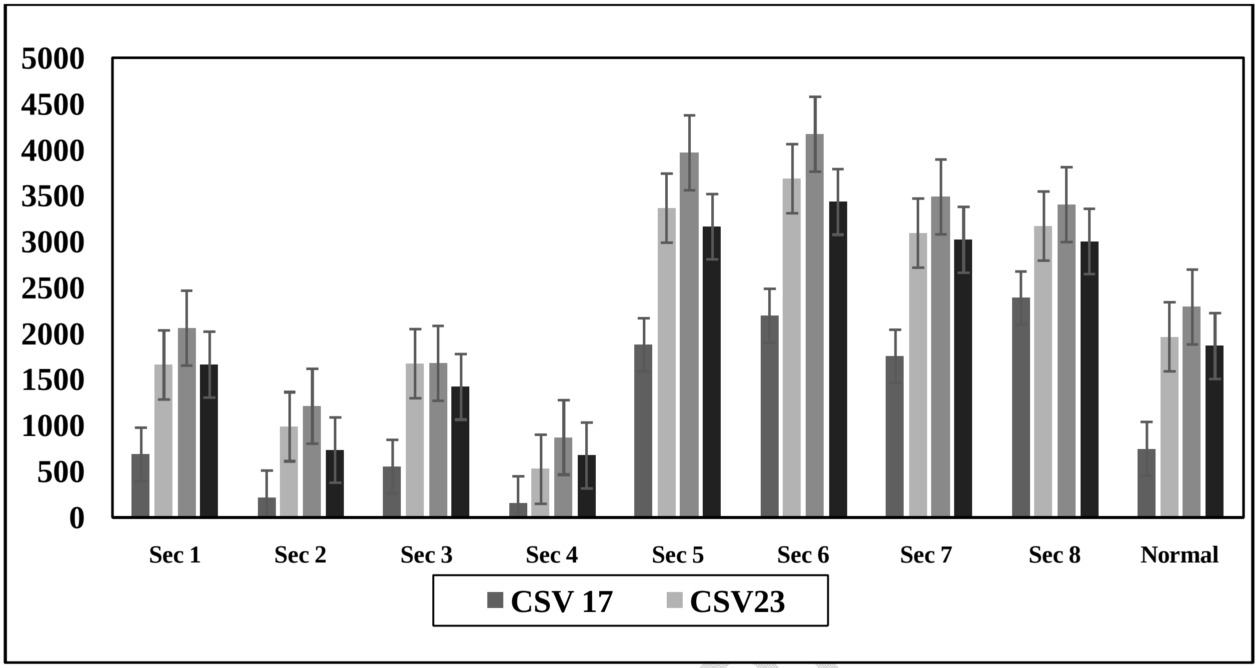

Fig. 1: Yield of four sorghum cultivars across different climate scenarios

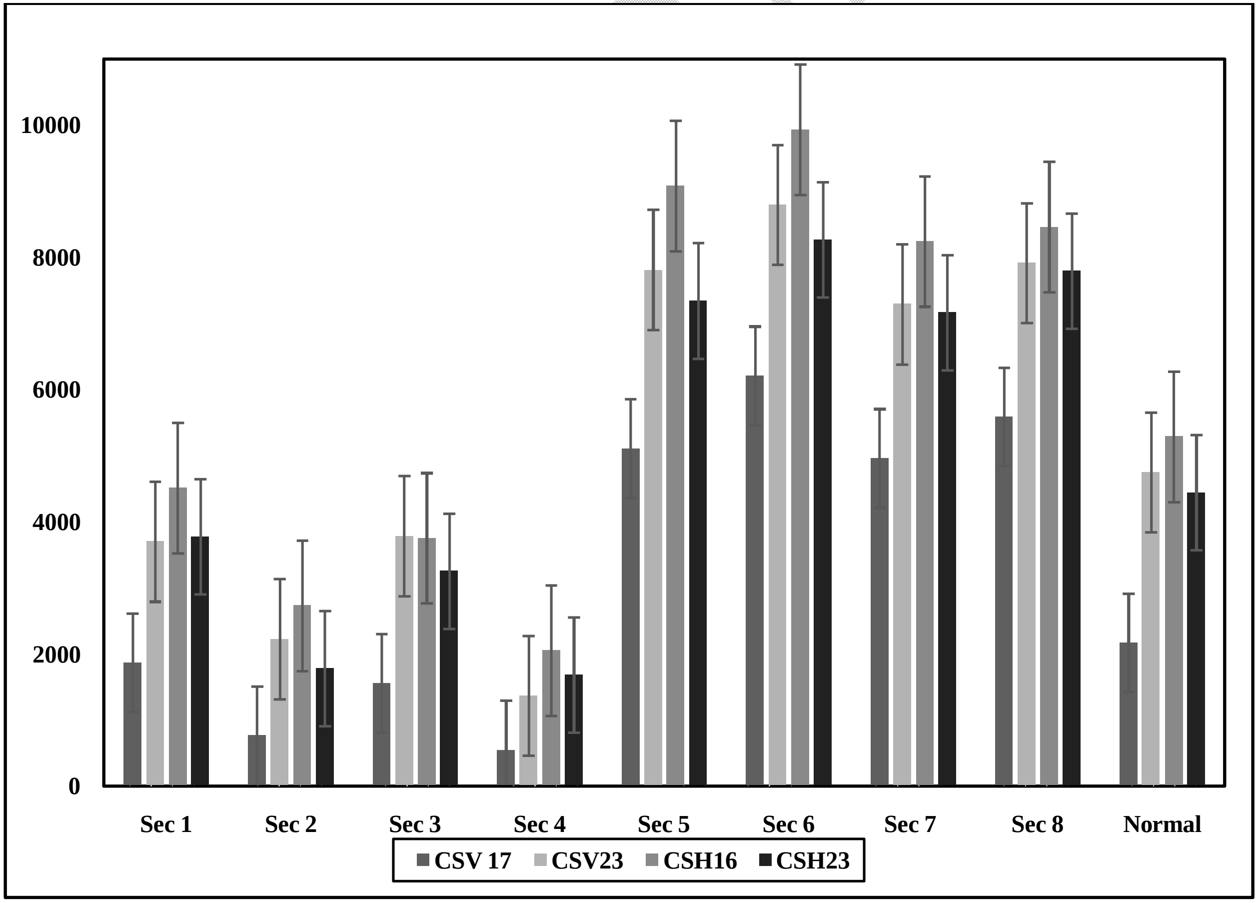

Fig. 2: DMP of four sorghum cultivars across different climate scenarios