Journal of Agrometeorology
ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 25 (4) : 532-538 (December - 2023)
https://doi.org/10.54386/jam.v25i4.2362
https://journal.agrimetassociation.org/index.php/jam

Research Paper

Long-term response of rainfed sorghum to diverse growing environments and optimal sowing window at Coimbatore

A. AMMAIYAPPAN[1], V. GEETHALAKSHMI[2*], K. BHUVANESWARI[3], M.K. KALARANI[4], N. THAVAPRAKAASH[5], and M. PRAHADEESWARAN[6]

[1]*Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore - 641003, Tamil Nadu, India*
[2]*Vice Chancellor, Tamil Nadu Agricultural University, Coimbatore - 641003, Tamil Nadu, India*
[3]*Centre for Agricultural and Rural Development Studies, Tamil Nadu Agricultural University, Coimbatore - 641003, Tamil Nadu, India*
[4]*Director Crop Management, Tamil Nadu Agricultural University, Coimbatore - 641003, Tamil Nadu, India*
[5]*Coconut Research Station, Tamil Nadu Agricultural University, Aliyarnagar - 642101, Tamil Nadu, India*
[6]*Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore - 641003, Tamil Nadu, India*
[*]*Corresponding author's email: geetha@tnau.ac.in*

ABSTRACT

Rainfed sorghum production is profoundly vulnerable to climate variability. Sowing the crop at an appropriate time could be one of the most crucial climate-resilient options to improve the yield. The well-calibrated and validated CERES-Sorghum model was employed to study the rainfed sorghum response to varied environments over the long term (1983–2021) and to determine the optimum sowing window at Coimbatore, Tamil Nadu. The CERES-Sorghum model was used for automatic-planting with a different minimum threshold of 50,60,70 and 80 percent soil water content at 15 cm soil depth under various sowing windows from 1stSeptember to 13th October at a 7-day interval. The model results of automatic planting event indicated the best performance of 1st September sowing window at 50 percent soil water content over 39 years under semi-arid environment. The temperature rise of 1˚C exhibited no significant influence on sorghum grain yields at all sowing windows and a slight reduction in yield was observed at an elevated 2˚C temperature. A further rise in temperature reduced the yield drastically on September month sowings. Across the sowing window, first week sowing window (1st to 7th September) yield was higher under current climatic conditions. The yield of 1st September sowing window remained higher in the elevated temperature conditions as well as in both deficit and excess rainfall conditions than other sowings. In current and future climatic conditions, 1st September sowing window would be the best sowing time to mitigate climate risk in rainfed sorghum.

Keywords: Rainfed sorghum, CERES-Sorghum, Sowing windows, Automatic planting, Elevated temperature.

Climate variability and change are escalating the levels of food crises and acute food insecurity around the globe. Increasing temperatures, erratic precipitation patterns, reduced precipitation, rising frequency of extreme events, *viz*., droughts and floods, and massive storm surges devastate the agriculture fields and have widespread substantial implications for socio-economic activities across the world (Affoh *et al*., 2022). The IPCC has emphasised that climate change triggered extreme weather events would cause multi-dimensional impacts on various sectors in the region that house vulnerable populations, especially in South Asia, including India (Elbasiouny *et al*., 2022). Agriculture faces 26% of the loss and damage in developing countries owing to climate-related calamities (Haig *et al*., 2019). The majority of rural populations are engaged in agriculture and rely on the monsoon for their livelihoods in arid and semi-arid regions, facing serious challenges.

The recently constructed Socioeconomic Pathways (SSPs) blend with radiative forcing levels of Representative Concentration Pathways (RCPs) under the Coupled Model Inter-Comparison Estimate 6 (CMIP6) has projected the climate and outlined in The Physical Science Basis report of Intergovernmental Panel on Climate Change's (IPCC's). In the very low Greenhouse

Article info - DOI: *https://doi.org/10.54386/jam.v25i4.2362*
Received: 15 September 2023; Accepted: 23 October 2023; Published online : 30 November, 2023

Gas Emission (GHG) scenario (SSP1-1.9), the average world surface temperature during 2081-2100 is likely to increase by 1.0°C to 1.8°C. It might rise up to 2.1°C to 3.5°C in the moderate scenario (SSP2-4.5), and 3.3°C to 5.7°C in the high GHG emissions scenario (SSP5-8.5). For every 1°C increase in global warming, extreme daily precipitation episodes are expected to worsen by roughly 7 per cent (Faranda *et al*., 2022). It is estimated that climate change might impair food security because it will have the greatest impact on the agriculture sector. Climate change is predicted to have a detrimental impact on production of wheat, rice, maize and sorghum in tropical and temperate regions, even with local temperature increases of 2°C (Challinor *et al*., 2014).

Across the country, India demonstrates significant variability in rainfall due to its unique geographical position, topography variations and increasing trends in the atmospheric temperature. In Tamil Nadu, water availability for agricultural production is becoming highly uncertain due to huge inter-seasonal and annual variations in rainfall. It experienced ten drought years during the last four decades (Rajkumar *et al*., 2020). Tamil Nadu has 45 percent of its gross cropped area under rainfed cultivation, which is vulnerable to the highly varying monsoon and frequent occurrences of drought.

Sorghum is an important nutraceutical crop for small and marginal farmers across the semi-arid tropics (SAT) of the world. Globally, sorghum is the fifth most important crop after rice, wheat, maize and barley, whereas in India it is the fourth largest crop. Sorghum is considered a climate smart crop that can be grown successfully under moisture stress conditions and with inadequate inputs (Chadalavada *et al*., 2021). In India, more than 90% of the sorghum cropped area is under rainfed conditions. At present, sorghum is being cultivated in both the monsoon (1.85 m ha) and post-rainy (2.89 m ha) seasons. In Tamil Nadu, the total area under sorghum cultivation is 4.05 lakh hectares, with a production of 4.27 lakh tonnes (Nagesh Kumar *et al*., 2022). Compared with the global average (1481 kg ha^{-1}) sorghum productivity in India is rather low, mostly because the crop is cultivated under rainfed conditions (Anbazhagan *et al*., 2022). According to IPCC sixth assessment report the average global surface temperature increased by 1.1°C in 2011-2020 compared to 1850-1900 and these changes have a significant influence on productivity of grain crops, including sorghum (Adak *et al*., 2023).

Achieving zero hunger and food security is a top priority in the United Nations Sustainable Development Goals (UNSDGs). In an era characterized by high population growth and increasing pressure on agricultural systems, efficiency in the use of natural resources has become central to sustainable agricultural practices. Selection of best sowing windows would maximise the crop production and also avoid economic losses significantly. The sowing time is critical factor for optimising sorghum grain yield. Consequently, farmers must understand the response of sorghum to the sowing windows. Improper sowing time would lead to serious damage or limit growth and development of the crops. The sowing time exerts a great influence on the growth and productivity of crops as it experiences varied environmental states. Analysis of long-term climate variability impact on sowing time offers an extensive understanding of potential risks associated with climate in crop production and helps determine appropriate sowing time. Conducting multi-year field experiments is costly and time-consuming, reliable, well-validated crop simulation models can be helpful under such conditions to simulate the long-term impact of climate variability on crops (Holzworth *et al*., 2014). The present study aimed to (i) understand the response of rainfed sorghum to varied growing environments (ii) explore the optimal sowing window for rainfed sorghum in western zone of Tamil Nadu.

MATERIALS AND METHODS

Experiment details

The present study was designed and conducted in the Department of Agronomy at Tamil Nadu Agricultural University, Coimbatore located at a latitude of 11° N and a longitude of 77°E with an altitude of 426.7 m above mean sea level (amsl). The sorghum [*Sorghum bicolor* (L.) Moench] crop variety K 12 (Kovilpatti 12) was planted with a spacing of 45×15 cm. All the agronomic practices were followed as per TNAU recommended practices for the crop. The recommended dose of fertilizer for irrigated sorghum (90:45:45 kg NPK ha^{-1}) were applied in the form of urea, single super phosphate and muriate of potash. Fifty percent of the recommended dose of nitrogen (RDN), the entire dose of phosphorous and potash were applied basally at the time of sowing. The remaining 50% of the nitrogen was applied by the two-split application on 15th day (25%) and 30th day (25%) after the sowing of sorghum. The dose of nitrogen was applied as per the treatments. The field experiment was carried out during the period 2022–2023, with different sowing dates and nitrogen levels to calibrate and validate the model. The experimental data collected during 2022 from three sowing dates (First fortnight of April, second fortnight of April, and first fortnight of May) fertilized with the recommended dose of nitrogen (RDN: 90 kg N ha^{-1}) and an increased level of nitrogen by 25% RDN (112.5 kg N ha^{-1}) was used for calibration. The independent dataset for the same treatments obtained from the experiment conducted in 2023 was utilized for validating the model. The soil, weather, and crop management files were created in CERES-Sorghum model using the soil profile data, crop growing environment and crop production practices followed in the experiments.

Model calibration and validation

The observed dates of anthesis, physiological maturity, and yield were compared with the simulated values to calibrate and validate the model using a set of statistical indices such as the root mean square error (RMSE) (Loague and Green 1991), index of agreement (d) (Willmott *et al*., 1985), Mean Absolute Percentage Error (MAPE) and coefficient of determination (r^2).

Seasonal analysis in model

The validated CERES-Sorghum model was employed to simulate grain yield for multiple years for rabi seasons using the seasonal analysis tool available in the model. The long-term weather data of 39 years (1983-2021) obtained from Agro Climate Research Centre (ACRC), TNAU was used for multiple-year simulations. The recommended sowing window for sorghum in western zone of

Tamil Nadu during *rabi* is September-October. The sorghum yield was simulated for multiple years under different sowing windows.

Sowing window modelling

The sowing is normally taken up in the first and second week of September by the farmers. In the present study, sowing windows were considered for *rabi* sorghum from 1 September to 13 October. The sowing was performed with a 7-day interval between each of the sowing window. In Tamil Nadu, 85 % of the sorghum area is under rainfed cultivation, and thus rainfall directly determines the planting time. Therefore, the automatic planting rules option available in CERES-Sorghum model was applied to take up sowing under a different sowing window. The automatic planting option of the model works in association with the soil water content specified in the model to evoke the planting event. The model prompted the planting when the desired soil water content was met in the given sowing window. The planting rule was kept in the model with a minimum threshold of four soil water content levels of 50,60,70 and 80 percent and an upper soil water content of up to 100 percent at 15 cm soil depth.

The model performed the automatic planting operation every year under a different sowing window when the automatic planting condition was attained. There are years where planting wasn't done if the auto planting condition wasn't met. In each sowing window, the number of years that had automatic planting and number of years with failed automatic events were counted for determining the best planting. The sowing window with maximum successful automatic planting years and the highest yield was identified as the best sowing window.

Climate change effect on sorghum

The individual and combined effects of temperature on sorghum were studied at different dates of sowing. The individual effects of temperature increase of 1,2,3,4 and 5 ^{o}C, rainfall increase of 10, 20, 30, 40 to 50%, and reduction of 10,20,30, 40 to 50 % on sorghum were studied. The combined effect of temperature and rainfall scenario were also investigated under different dates of sowing.

RESULTS AND DISCUSSION

Determination of genetic coefficient

The growth and yield contributing parameters were adjusted until a satisfactory match was achieved between the model's simulated and observed growth and yield parameters by repeated iterations as per procedure given by Amouzou *et al*., (2018). The derived genetic coefficient values for K12 are furnished in Table 1.

Model calibration and validation

The calibration results indicated the RMSE for anthesis physiological maturity and grain yield were 2.78 days, 3.28 days and 300.17 kg ha^{-1} respectively. At the same time, the BIAS, MAPE, r^2 and D values were also calculated for the same parameters. The BIAS for anthesis was 4.6%, physiological maturity was 3.5% and sorghum grain yield was 7.1%. The MAPE observed for anthesis, physiological maturity and sorghum grin yield was 4.56, 3.50 and 7.14 respectively. The r^2 value for anthesis was 0.94, physiological maturity was 0.93 and the grain yield is 0.81. The d-statistics for anthesis was 0.76, physiological maturity was 0.73, and grain yield was 0.80. The results clearly demonstrated an adequate agreement between the observed and simulated anthesis, physiological maturity and the sorghum grain yield (Table 2). It is evident from the results that the crop model's cultivar-specific parameters (genetic coefficients) were appropriately modified and defined the characteristics of the test cultivar.

The statistical test for validation showed high goodness of fit with the r^2 value of 0.95 for anthesis, 0.93 for physiological maturity and 0.85 for sorghum grain yield, indicating good performance of model. The d statistical value (D value) was 0.78 for anthesis, 0.71 for physiological maturity and 0.83 for grain yield. The BIAS for anthesis, physiological maturity and sorghum grain yield were 3.9%, 4.5% and 5.3% respectively. The MAPE was found to be 3.94 for anthesis, 4.46 for physiological maturity and 5.31 for sorghum grain yield. RMSE values of 2.56 for anthesis and 3.49 days for physiological maturity and for grain yield of 248.1 kg ha^{-1} exhibit a good analogy between the simulated and observed values.

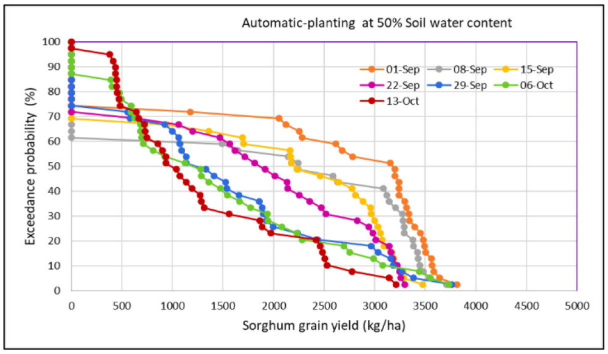
The r^2 values obtained above 0.8 for both calibration and validation indicated a good association between observed and model simulated data. The BIAS value indicated that CERES-Sorghum model simulated values were marginally higher than the observed values. The satisfactory D values showed the strong capability of the model in predicting the sorghum grain yield. The examination of the model revealed that the simulated and actual values fitted quite well, demonstrating the efficacy of the model in simulating phenology (anthesis and flowering) in the semi-arid environment. The findings also suggested that the model may be applied to a variety of tasks, including determining the optimum sowing window for sorghum production in the research region's present and future climate conditions and examining how climate change will affect sorghum productivity.

Long-term variability in sowing window

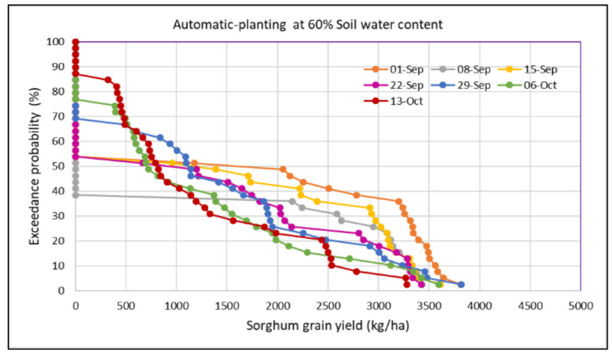
Analysis of results on automatic planting events over 39 years revealed (Table 3) that the number of years with automatic planting was higher in October sowing windows compared to September sowing windows at all given minimum thresholds of soil water content levels, *viz*., lower soil-water content levels of 50, 60, 70, and 80 percent. A lower number of failed auto-planting events was observed with October sowing than with September sowing. Among the September sowing windows, the 1st September sowing window (first week of September) had the highest number of successful automatic planting events (28) at 50 percent lower soil water content which is on par with 22nd September sowing window. However, it is comparable with other sowing windows except the 8th sowing window, with a difference of up to two events. The 1st September sowing windows demonstrated the 20 events at 60 percent lower soil water content, which is on par with the 15th September and 22nd September sowing windows. At 60,70 and 80 percent lower soil water content, the 29th September sowing window showed the highest number of years of planting, with

Table 1: Genetic co-efficient of sorghum variety K 12

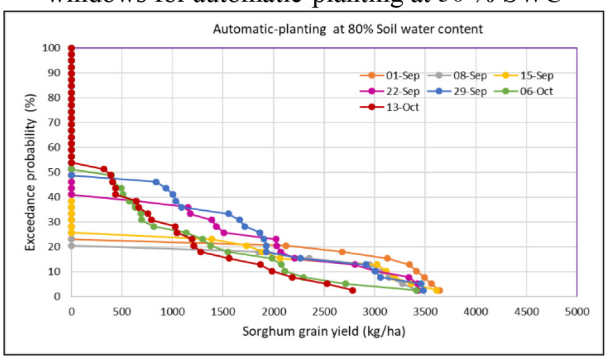
P1	P2	P2O	P2R	PANTH	P3	P4	P5	PHINT	G1	G2
410	88	11.7	88	550.5	130	75.5	530	60	5.1	6.6



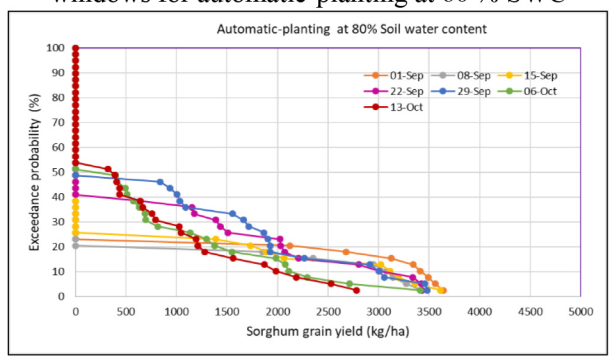
(a). Sorghum grain yield under various sowing windows for automatic-planting at 50 % SWC



(b). Sorghum grain yield under various sowing windows for automatic-planting at 60 % SWC



(c). Sorghum grain yield under various sowing windows for automatic-planting at 70 % SWC



(d). Sorghum grain yield under various sowing windows for automatic-planting at 80 % SWC

Fig. 1: Probability of exceedance for sorghum grain yield across seven sowing windows with automatic planting under four levels of soil water content

26, 24 and 18 years, respectively in September sowing windows. More failed automatic planting was observed in the 8th September sowing window at all lower soil water content levels. Regarding the October sowing window, 13th October recorded the highest automatic planting events of 36, 33, 28 and 20 at 50, 60, 70, and 80 percent content, respectively. The higher number of years with successful events of automatic planting at all soil water levels in October than September can be attributed to the higher amount of rainfall received during the October sowing window period (Yadav *et al*., 2015). Similarly, the late sowing window (29th September) of September had the highest occurrence of automatic planting at increased soil water content levels associated with the receipt of increased rainfall during that sowing window (Vishnoi *et al*., 2020).

Long-term sorghum yield variability under different sowing window

The weather conditions that prevail during the crop growing season mainly determine crop growth and productivity. Analysis indicated that the sorghum grain median yield attained its peak at the 1st September sowing window and thereafter declined towards the sowing window, progressing at a 7-day interval till the 13th October sowing window under 50, 60, and 70 percent soil water content. The September sowing window up to 22nd September showed that 50 percent of the years didn't meet the criteria of the 70 percent soil water content set for automatic planting, which led to no crop in 50 percent of years. Further, 100 percent of years exhibited zero yield due to the fact that all years had no crop at the present condition of 80 percent soil water content for automatic planting up to 15th September sowing window. The highest average yield produced under 1st September the sowing window found to be 2235 kg ha^{1} and the lowest average yield of 1214 kg ha^{1} was recorded under 13th October sowing window at 50 per cent soil water content. The second maximum median yield was noticed in September 15 sowing window with average yield of 1808 kg ha^{1} and 1383 kg ha^{1} at 50 and 60 percent soil water content respectively. The coefficient of variation (CV) of the grain yield is less at 50% soil water content, and it is on the increasing side when the requirement of soil water content increases for the occurrence of automatic planting. Less variability over the years was observed with automatic planting at 50% and 60 % soil water content compared to automatic-planting done at 70 and 80 % soil water content. The lower CV values at lower soil water content might be linked to the number of years that had enough predetermined moisture to trigger the automatic planting, which resulted in a minimum failure of the automatic planting event and less inter-annual variability at different sowing windows (Akinseye *et al*., 2023). In contrast, more years of

Table 2: Comparison between simulated and observed anthesis date, physiological maturity (days), grain yield of K 12 sorghum cultivar during model calibration and validation

Parameters	Calibration			Validation		
	Days to anthesis	Days to physiological maturity	Grain yield (kg ha^{-1})	Days to anthesis	Days to physiological maturity	Grain yield (kg ha^{-1})
Observed	60	93	3795	59	91	3569
Simulated	63	96	4063	62	94	3755
r2	0.94	0.93	0.81	0.95	0.93	0.85
d	0.76	0.73	0.8	0.78	0.71	0.83
RMSE	2.78	3.28	300.17	2.56	3.49	248.1
BIAS (%)	4.6	3.5	7.1	3.9	4.5	5.3
MAPE	4.56	3.5	7.14	3.94	4.46	5.31

Table 3: Sowing window with the number of automatic planting years at various soil water content thresholds

Sowing window (7-day interval)	Planting occurred - No. of years and percentage of years (%)			
	50 % SWC	60%SWC	70%SWC	80% SWC
01-Sep	28 (72)	20 (51)	12 (31)	8 (21)
08-Sep	23 (59)	14 (36)	11 (28)	7 (18)
15-Sep	26 (67)	20 (51)	15 (38)	9 (23)
22-Sep	27 (69)	20 (51)	19 (49)	15 (38)
29-Sep	28 (72)	26 (67)	24 (62)	18 (46)
6-Oct	33 (85)	29 (74)	24 (62)	19 (49)
13-Oct	37 (95)	33 (85)	28 (72)	20 (51)

SWC: Soil water content, the percentage of years is given in parenthesis

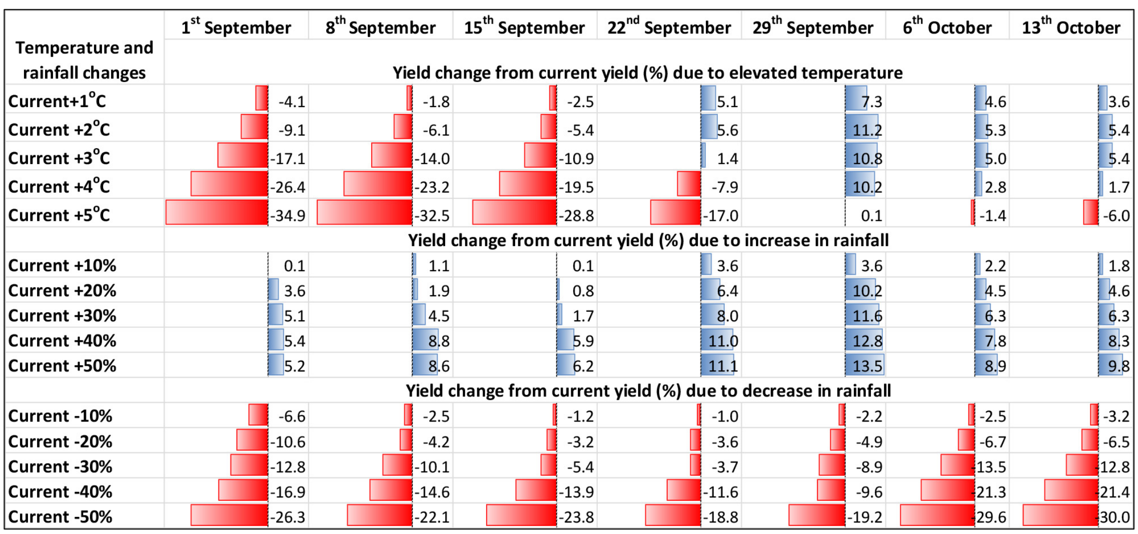


Fig. 2: Effect of elevated temperature and rainfall changes on sorghum yield

failed planting events occur when soil water content is fixed to be increased to incite automatic planting, leading to more CV. At lower soil-water content, the planting event is more dependable, indicating a higher possibility of taking up sowing with more confidence under different sowing windows during the rabi season.

The exceedance probability of sorghum grain yield under each sowing window (Fig. 1) demonstrated a greater difference for automatic-planting at various soil water content levels.

The automatic-planting at early sowing window (1st September) showed that there is about 70 % probability for getting yield above zero while the late sowing window had the higher probability of about 95 % for obtaining yield exceeds zero with the automatic-planting at 50 % soil water content. However, the maximum chance of obtaining higher grain yield was observed in early sowing window crop at automatic-planting under all 50, 60,70 and 80 % soil water content levels and thereafter the probability of getting lower grain yields was found at automatic-planting under various soil water content. Such variations were related to prevailing rainfall during growing period of sorghum crop. In general, early sown crops during *rabi* receive a sufficient amount of rainfall at all the growth and reproductive phases, while late sown crops suffer moisture stress from the beginning of reproductive stage till the end of harvest, thus producing a lower yield (Singh, 2023). The vegetative and reproductive stages of the crop are the most important crop stages that determine crop production, water stress at this stage lowering the crop yield by more than 35% and 50%, respectively (Gohain *et al*., 2022).

Impact of elevated temperature and rainfall changes on sorghum

Crop growth and productivity are mainly determined by the weather conditions that prevail during the growing season. Rainfall and temperature are the most critical environmental factors that play a predominant role in determining the growth and productivity of crops (Praveen and Sharma, 2019). The impact of elevated temperature and rainfall changes on sorghum yield was assessed with automatic planting at 50% soil water content under different sowing windows. It was observed that among the sowing windows, the 1st September sowing window performed well with a higher median yield under the current climatic conditions and also modified environmental conditions. The effect of elevated temperatures and rainfall on sorghum productivity is presented in Fig. 2. In the 1st September sowing window, the increase in temperature by 1°C to 5°C reduced the yield by 4.1 to 34.9%. The yield declined by 1.8 to 32.5% in 8th September, 2.5 to 28.8% in 15th September sowing window with respect to an elevated temperature of by 1°C to 5°C. An increase in temperature beyond certain level drastically reduced the yield (Rai *et al*., 2021). An increase in temperature above optimum range in the early sowing windows might have led to flower drop, poor pollination, less grain filling and also reduced grain size and subsequently a decline in grain yield (Prasad *et al*., 2006). The 22nd September sowing window demonstrated the positive effect by the yield improvement of 5.1, 5.6 and 1.4 % at the 1°C, 2°C and 3°C respectively while above 3°C increase in temperature showed a negative effect during that sowing window. The temperature increases of up to 4°C increase uplifted the yield in the rest of the sowing windows might be due to the exposure of crops to the optimal temperature range grown under the late sowing window. The maximum yield increase of 5, 9,6,11,14,9 and 10 % was observed at the 1st September, 8th September,15th September,22nd September, 29th September, 6th October and 13th October sowing window respectively due to the increased rainfall of up to 50%.

The magnitude of the effect posed by reduced rainfall is larger than the increased rainfall that caused the yield losses of up to 30 % across the sowing with 50% reduction in rainfall. Despite the fact that the last three sowing windows from 29th September to 13th October experienced the advantageous effect of an elevated temperature of up to 4°C the 1st September sowing window (early sowing window) exhibited a higher yield among all the sowing window. Similarly, 1st September sowing window showed a higher yield under both deficit and excess rainfall of 50 % over other sowing windows. The sufficient rainfall received in the 1st September sowing window might have favoured the productivity of sorghum.

CONCLUSION

The study highlighted the response of sorghum sown at the required moisture through the automatic planting option available in CERES-Sorghum model under different sowing windows over the 39 years (1983-2021). Sowing the sorghum crop at different moisture levels influenced the rainfed sorghum yield. The automatic planting done at the first week sowing window under 50% soil water content showed higher yield than other soil water content levels and sowing windows. In the first three sowing window at 7 days interval from 1st September up to 15th September, every degree increases in temperature showed a detrimental effect on sorghum and 22th September sowing window up to 3°C increase in temperature rendered beneficial effects to the sorghum crop. However, a more than 3°C increase in temperature negatively affected the crop sown during the 22th September sowing window. The elevated temperature of up to 5°C positively influenced the yield of the crop sown in 29th September sowing window. Similarly, 6th October and 13th October sowing window benefited from the increase in temperature up to 4°C and beyond 4°C caused deleterious effect on sorghum productivity. The rainfall increases of 50 % increased the yield to a certain extent, with the maximum increase of 13.5 percent in 29th September sowing window. The reduction in rainfall decreased the yield in all the sowing windows. In the first three sowing windows the magnitude of the adverse effect of elevated temperature was higher compared to the effect of reduced rainfall whereas in three sowing windows a reduction in rainfall led to yield loss but elevated temperature improved the yield. The present investigation indicated that appropriate time of sowing utilizing the availability of required soil moisture would improve rainfed sorghum productivity.

ACKNOWLEDGEMENT

The authors thank to the Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, for extending their guidance and technical assistance in conducting this research work.

Funding: The first author is grateful to the University Grants Commission (UGC), Government of India, for providing the funding support to carry out the research through UGC- NET-SRF.

Conflict of interest: The authors are declaring that there is no conflict of interest in the publication of the paper

Data availability: The used data for this study are available in the manuscript

Authors contributions: **A. Ammaiyappan:** Execution, experimentation, analysis, manuscript writing and editing; **V. Geethalakshmi**: Idea generation, supervision, reviewing; **K. Bhuvaneswari**: Data curation, Data analysis using R software, plot creation; **M.K. Kalarani**: Supervise the field experiment, guidance and reviewing; **N. Thavaprakaash**: Conceptualization, Guidance and reviewing; **M. Prahadeeswaran**: Guidance and reviewing

Disclaimer: The contents, opinions, and views expressed in the short research communication published in the Journal of Agrometeorology are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

Publisher's Note: The periodical remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

REFERENCES

Adak, S., Mandal, N., Mukhopadhyay, A., Maity, P.P., Sen, S. (2023). Current State and Prediction of Future Global Climate Change and Variability in Terms of CO_2 Levels and Temperature. In: Naorem, A., Machiwal, D. (eds) Enhancing Resilience of Dryland Agriculture Under

Changing Climate. *Springer*, Singapore. https://doi.org/10.1007/978-981-19-9159-2_2.

Affoh, R., Zheng, H., Zhang, X., Yu, W. and Qu, C. (2022). Influences of Meteorological Factors on Maize and Sorghum Yield in Togo, West Africa. *Land*, 12(1), 123.

Akinseye, F. M., Ajeigbe, H. A., Kamara, A. Y., Omotayo, A. O., Tofa, A. I. and Whitbread, A. M. (2023). Establishing optimal planting windows for contrasting sorghum cultivars across diverse agro-ecologies of north-eastern Nigeria: a modelling approach. *Agron.*, 13(3), 727.

Amouzou, K. A., Naab, J. B., Lamers, J. P. A. and Becker, M. (2018). CERES-Maize and CERES-Sorghum for modeling growth, nitrogen and phosphorus uptake, and soil moisture dynamics in the dry savanna of West Africa. *Field Crops Res.*, 217, 134–149.

Anbazhagan, K., Voorhaar, M., Kholová, J., Chadalavada, K., Choudhary, S., Mallayee, S. and Selvaraj, A. (2022). Dual-Purpose Sorghum: A Targeted Sustainable Crop-Livestock Intervention for the Smallholder Subsistence Farming Communities of Adilabad, India. *Front. Sustain. Food Syst.*, 6, 742909.

Chadalavada, K., Gummadi, S., Kundeti, K. R., Kadiyala, D. M., Deevi, K. C., Dakhore, K. K. and Thiruppathi, S. K. (2021). Simulating potential impacts of future climate change on post-rainy season sorghum yields in India. *Sustainability*, 14(1), 334.

Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R. and Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. *Nat. Clim. Change.*, 4(4), 287-291.

Elbasiouny, H., El-Ramady, H., Elbehiry, F., Rajput, V. D., Minkina, T. and Mandzhieva, S. (2022). Plant nutrition under climate change and soil carbon sequestration. *Sustainability*, 14(2), 914.

Faranda, D., Bourdin, S., Ginesta, M., Krouma, M., Noyelle, R., Pons, F. and Messori, G. (2022). A climate-change attribution retrospective of some impactful weather extremes of 2021. *Weather & Clim. Dyn.*, 3(4), 1311-1340.

Gohain, G. B., Singh, K. K., Singh, R. S., Dakhore, K. K. and Ghosh, K. (2022). Application of CERES-sorghum crop simulation model DSSAT v4. 7 for determining crop water stress in crop phenological stages. *Model. Earth Syst. & Environ.*, 8(2), 1963-1975.

Haig, S. M., Murphy, S. P., Matthews, J. H., Arismendi, I. and Safeeq, M. (2019). Climate-altered wetlands challenge waterbird use and migratory connectivity in arid landscapes. *Sci. Rep.*, 9(1), 4666.

Holzworth, D. P., Huth, N. I., deVoil, P. G., Zurcher, E. J., Herrmann, N. I., McLean, G. and Keating, B. A. (2014). APSIM–evolution towards a new generation of agricultural systems simulation. *Environ Model Softw.*, 62, 327-350.

Loague, K. and Green, R. E. (1991). Statistical and graphical methods for evaluating solute transport models: overview and application. *J. Contam. Hydrol.*, 7(1-2), 51-73.

Nagesh Kumar, M. V., Ramya, V., Govindaraj, M., Dandapani, A., Maheshwaramma, S., Ganapathy, K. N. and Jagadeeshwar, R. (2022). India's rainfed sorghum improvement: Three decades of genetic gain assessment for yield, grain quality, grain mold and shoot fly resistance. *Front. Plant Sci*, 13, 1056040.

Prasad, P. V., Boote, K. J. and Allen Jr, L. H. (2006). Adverse high temperature effects on pollen viability, seed-set, seed yield and harvest index of grain-sorghum [Sorghum bicolor (L.) Moench] are more severe at elevated carbon dioxide due to higher tissue temperatures. *Agric. For. Meteorol.*, 139(3-4), 237-251.

Praveen, B. and Sharma, P. (2019). A review of literature on climate change and its impacts on agriculture productivity. *J. Public Aff.*, 19(4), e1960.

Rai, S. K., Kumar, S. and Chaudhary, M. (2021). Detection of annual and seasonal temperature variability and change using non-parametric test-A case study of Bundelkhand region of central India. *J. Agrometeorol.*, 23(4), 402-408. https://doi.org/10.54386/jam.v23i4.144

Rajkumar, R., Shaijumon, C. S., Gopakumar, B. and Gopalakrishnan, D. (2020). Extreme rainfall and drought events in Tamil Nadu, India. *Climate Res.*, 80(3), 175-188.

Singh, P. (2023). Crop models for assessing impact and adaptation options under climate change. *J. Agrometeorol.*, 25(1), 18-33. https://doi.org/10.54386/jam.v25i1.1969

Vishnoi, L., Kumar, A., Kumar, S., Sharma, G., Baxla, A. K., Singh, K. K. and Bhan, S. C. (2020). Weather based crop insurance for risk management in agriculture. *J. Agrometeorol.*, 22(2), 101-108. https://doi.org/10.54386/jam.v22i2.149

Willmott, C. J., Ackleson, S. G., Davis, R. E., Feddema, J. J., Klink, K. M., Legates, D. R. and Rowe, C. M. (1985). Statistics for the evaluation and comparison of models. *J. Geophys. Res. Oceans.,* 90 (C5), 8995-9005.

Yadav, M. K., Singh, R. S., Singh, K. K., Mall, R. K., Patel, C. B., Yadav, S. K. and Singh, M. K. (2015). Assessment of climate change impact on productivity of different cereal crops in Varanasi, India. *J. Agrometeorol.*, 17(2), 179-184. https://doi.org/10.54386/jam.v17i2.1000