A simulation study on the effects of climate change and potential management strategies for sorghum [Sorghum bicolor (L.) Production of Moench in Northeastern Ethiopia's Semi-Arid Region

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Research Article

Date of Submission: 10-12-2025
Date of Acceptance: 22-01-2026
Date of Publication: 25-03-2026

ABSTRACT

One of the contemporary problems that has a significant impact on all climate-sensitive industries, including agriculture, is climate change. To reduce the effects and maintain local food supply, crop management strategies are required.The study's goals were to: (1) calibrate and assess the CERES-Sorghum Model of DSSAT (V4.7) for simulating sorghum phenology, growth, and yield; (2) evaluate projected climate changes (2030s and 2050s) in the study area; (3) simulate the impact of projected climate change on sorghum phenology, above-ground biomass, and grain yield; and (4) investigate the possibility of using sorghum cultivars and supplemental irrigation as management options. Using experimental data, the CERES-sorghum model in DSSAT (V4.7) was initially calibrated and assessed for the sorghum cultivar Girana-1. The closest weather station in Sirinka, Ethiopia, provided daily meteorological data from 1980 to 2009, including rainfall, maximum and minimum temperatures, and sun radiation. CIAT's climate change portal (http://ccafs-climate.org/) provided the 17 CMIP5 GCM outputs ran under RCP 4.5 and RCP 8.5 for the 2030 and 2050 time slices, which were then downscaled to the target locations using Markism GCM. According to the model calibration result, the model's cultivar-specific parameters were appropriately modified. With a minimal RMSE of 1.83 for anthesis, 3.3 for physiological maturity, 685.6 for grain yield, and 477.8 for above-ground biomass yield, the model assessment results also demonstrated that it accurately replicated phenology, grain yield, and above-ground biomass yield. According to the study of the future climate, the mean maximum temperature is expected to rise by 1.40C and 1.90C by the 2030s and 2050s time periods, respectively, under RCP 4.5, and by 1.50C and 2.50C by the 2030s and 2050s time phases, respectively, under RCP 8.5. According to RCP 4.5, rainfall is expected to rise by 1.5% and 4.5% in the 2030s and 2050s, respectively, and by 3.7% and 3.2% in the 2030s and 2050s, respectively, under RCP 8.5. Sorghum phenology is expected to decline considerably ($P < 0.05$) in the 2030s and 2050s. Nonetheless, a large ($P < 0.05$) rise in sorghum grain output is anticipated in the 2030s and 2050s. The modeling results also indicated that long-maturing cultivars and more irrigation will significantly boost sorghum grain output under future climatic conditions.

Keywords: Climate change; crop model; DSSAT; more irrigation; RCP; Sorghum

INTRODUCTION

The majority of Ethiopians make their living from agriculture, which also serves as the foundation of the country's economy, which is dominated by small-scale subsistence farming. Over 80% of workers are employed in this industry, which also generates 45% of the GDP and 85% of export earnings [1]. Less than 1% of Ethiopia's total cultivated area is used for irrigated agriculture, and the country's agriculture is mostly reliant on natural rainfall. Food shortages and famine may result from the quantity and timing of rainfall and other climatic elements throughout the growing season, which are crucial to crop output.The traditional farming method in Ethiopia's lowlands is totally dependent on a rainfed agricultural production system, which is marked by low yields and poor crop performance. Moisture stress, low soil fertility, Strigahermonthica, and restricted availability to better seed and effective production practices are the main causes of low yields. The region's unpredictable rainfall patterns are the primary factor affecting agricultural production [2]. Rainfall is inadequate, distributed unevenly, and unpredictable [3]. One of the main issues influencing agricultural output globally is drought. Droughts will occur more often as a result of climate change, especially in many already drought-prone African nations. 67% of the world's population is expected to be impacted by water scarcity by 2050 [4]. Drought is more likely to occur during the beginning and conclusion of the growing season in the dry and semi-arid tropics. While drought stress during the blooming or grain-filling phases may lead to decreased establishment, decreased yield, or total crop failure, drought stress at the start of the growing season significantly influences plant establishment [5].Crop output will be under pressure and unpredictable as a result of climate change brought on by greenhouse gas emissions, which is predicted to raise temperatures and disrupt precipitation patterns. The first industry to suffer from climate change and unpredictability is agriculture. It is anticipated that crop output in these areas would suffer [6]. Agricultural output is susceptible to the effects of climate change due to its sensitivity, adaptability, and level of exposure [7]. Climate is a major factor in determining food security since around 89% of cereals in sub-Saharan Africa are rainfed [8, 9]. The scientific literature is increasingly in agreement that rising temperatures and shifting precipitation patterns brought on by climate change will reduce agricultural yields in many nations during the next decades [10]. In low-income nations, where adaptive ability is thought to be limited, this is especially important [11]. Many African nations are especially susceptible to climate change since their economies are mostly dependent on weather-sensitive agricultural output [10]. The kind of crop and development stage determine how much of an influence climate change has. Crops react differently to changes because they vary genetically and phenotypically. Due to the dominance of a small number of cereal crops, agricultural output in arid and semi-arid regions is less diverse. Therefore, it is crucial to pay attention to crops that are vital to develop and generate a respectable amount in such tough situations. After maize, rice, wheat, and [12], sorghum (Sorghum bicolor (L.) Moench) is the fifth most significant cereal crop worldwide. About 300 million people in sub-Saharan Africa rely on this important crop for food security. It is cultivated in marginal and drought-prone regions in semi-arid zones where other crops are unreliable. Sorghum, which ranks second in overall output after maize, is a significant staple food crop in Ethiopia [13]. In terms of production per hectare, it comes in third place after wheat and maize, while in terms of cultivated area, it comes in third place behind tef and maize. It is cultivated on 1.8 million hectares of land in almost every region [13]. Crop and climate scenarios may be used to evaluate how climatic variability affects sorghum output in various regions of the globe. The prediction of climate behavior on many time scales, including seasonal, annual, decadal, and centennial, is improved by the use of climate models. Models aid in determining the degree to which natural variability, human activity, or both may be responsible for observed climate fluctuation and change. At the national, regional, and local levels, climate model results and forecasts provide crucial information that may be used to make well-informed choices. Prior evaluations of the effects of climate change on Ethiopia's agricultural output were either conducted at the national level [14] or at a broader scale, such as the East African regional level [15]. In Ethiopia, there are very few research conducted at the municipal or subnational levels [16]. Therefore, while planning and creating suitable management methods, it is essential to comprehend how climate change affects sorghum yields at local scales. The effect of climate change on sorghum production at the local level has been the subject of very few research. Consequently, our research made an effort to bridge this gap.

determining how the study area's temperature and rainfall are anticipated to vary in the future, how these changes will impact sorghum output, and how adaption strategies might improve future sorghum production in the semiarid environment of northeastern Ethiopia. Computer technology advancements have made it feasible to take into account the combined impact of several aspects in a variety of interactions. To anticipate agricultural output more precisely, the soil, plant, and climate systems may be quantitatively combined. Modeling is the process of representing a system's behavior using equations or groups of equations. By forecasting the development of a crop's constituent parts, such as leaves, roots, stems, and grains, models mimic the behavior of actual crops. Soil fertility, water and irrigation management, yield gap analysis, genotype by environment interaction in plant breeding, climate change and climatic variability, risk insurance, and adaptive management have all been studied using the DSSAT Model [17]. The use of crop modeling techniques to evaluate the effects of climate change on crops has drawn a lot of interest lately, offering a solution in terms of lowering costs and increasing knowledge. The DSSAT model has been used all over the globe to predict soil nitrogen (N) dynamics and crop biomass and yield under varied climatic conditions and management techniques [18]. The models must constantly be tested and updated in a variety of settings and cropping techniques [19]. Therefore, the purpose of this study was to calibrate and assess the CERES-Sorghum model of DSSAT in the study region, forecast future climate change in the study area, forecast the impact of projected climate change on sorghum production, and assess the impact of supplemental irrigation on sorghum productivity as a management option in the semiarid environment of northeastern Ethiopia.

MATERIALS AND METHODS

Description of the study area

The experiment was carried out in the Sirinka Agricultural Research Center research site, which is situated in the semi-arid region of northeastern Ethiopia, during the 2018–2019 main cropping season. The region is located in latitude 110 45'00" and longitude 390 36'36" at an elevation of 1850 meters above sea level (m.a.s.l.). The research region is often described as semi-arid, with rainfall that is very unpredictable, low in quantity, and unevenly distributed [20]. The region has a maximum temperature of 27.3°C and a low temperature of 13.6°C, with an annual rainfall of around 945 mm. The region's soil type is Eutric Vertisol.

Experimental procedure

On a plot of 10 m by 10 m, the sorghum cultivar (Girana-1) was sowed three times at a spacing of 75 cm by 15 cm. While nitrogen fertilizer in the form of urea was administered in split at a rate of 50 kg ha-1, or half at planting time and the other half 35 days after the crop emerged, recently advised blended fertilizer (NPS) was used during planting at a rate of 100 kg ha-1. In accordance with local recommendations, additional crop management techniques were used for the cultivar. The Sirinka Agricultural Research Center provided phenology, growth, and yield data from field experiments conducted in 2013, 2015, and 2017 for the model's assessment.

Description of the DSSAT model

One of the most popular modeling systems in the world is DSSAT (Decision Support System for Agro-technology Transfer). Models representing 32 distinct crops, including a number of cereal grains, grain legumes, and root crops, may now be included into the DSSAT shell [21]. One of the first packages to modify weather simulation generators was the Decision Support System for Agro-technology Transfer (DSSAT), which also offered a package to assess model performance in climate change scenarios. The models are process-oriented and designed to function regardless of crop cultivar, season, region, or management technique. The models replicate how crop development and production are impacted by weather, soil water, genotype, and soil and crop nitrogen dynamics [22]. Applications for

DSSAT and its crop simulation models are many and include anything from precision and on-farm management to regional impact assessments of climate change and variability. DSSAT is a software program that integrates the impacts of soil, crop genotype, weather, and management choices. It enables users to simulate outcomes and pose "what if" questions by running experiments that would take up a large portion of an agronomist's career on a desktop computer in a matter of minutes.

Description of the (CERES)-sorghum model

One of the elements of the DSSAT model is the Crop-Environment-Resource-Synthesis (CERES)-Sorghum model. Carbon balance, water balance, nitrogen balance, and vegetative and reproductive development are the main elements of the model [23]. Using a daily time step from planting to maturity, it models the growth and development of sorghum and eventually forecasts yield. Genetic coefficients, or cultivar-specific factors, are inputs to the model that influence genotypic variations in crop cultivar growth, development, and yield. The model also included the impact of soil properties on water availability for crop development, as well as physiological mechanisms that explain how crops react to important meteorological elements like temperature, precipitation, and sun radiation.

Calibration and evaluation of the CERES-sorghum model

Sorghum growth, development, and yield were simulated using the DSSAT system's CERES-sorghum model, version 4.7. Model calibration is the process of modifying a model's parameters and functions to make predictions that match or closely resemble the evidence gathered from field experiments. Certain settings often need small modifications [24]. Genetic coefficients that characterize each cultivar's phenology, growth, and yield traits are needed for the CERES-sorghum model. The field experiment carried out in 2018 at the research site of Sirinka Agricultural Research Center, which is situated in semi-arid northeastern Ethiopia, provided the data used in this work to calibrate the model. Phenological and yield data from the Sirinka Agricultural Research Center for the years 2013, 2015, and 2017 were used to assess the crop model. The calibration was achieved by establishing a small modification (±5%) of each parameter using the "Trial and Error" approach. Adjusting the genetic coefficients that govern phenology was the initial stage, followed by yield and yield components. The model's subsequent assessment made use of the coefficients. The coefficient of determination (R2) and the index of agreement (d) were used to statistically compare the simulated and actual dates of anthesis, physiological maturity, and yield.

Willmott et al., (2015) and the mean square error (RMSE).

The model evaluation stage is the confirmation that the calibrated model closely represents the real situation. The CERES-maize model was evaluated using field experimental data of 2013, 2015 and 2017 based on phenology, yield and yield components and growth parameters. A set of statistical methods were applied to evaluate the performance of this model, including Root Mean Square Error (RMSE), normalized root mean square error (nRMSE), mean deviation (MD),mean absolute error (MAE),and index of agreement (d).

.....................................1 $$\mathrm{RMSE} = \frac{\sum_{i=1}^{n}(\sqrt{(Pi-Oi)^2}}{N}$$

Where N is the number of observed values and Oi and Pi are observed and predicted values, respectively for the ith data pair

$$\mathrm{N\ RMSE} = \frac{\mathrm{RMSE}}{N} \times 100$$ ……………….........……..2

Where NRMSE is normalized root mean square error express in percent. RMSE is root mean square error. N is the mean of the observed variable. Normalized RMSE gives a measure (%) of the relative difference of simulated versus observed data. The simulation is considered excellent when a normalized RMSE is less than 10%, good if the normalized RMSE is greater than 10 and less than 20%, fair if the normalized RMSE is greater than 20% and less than 30%, and poor if the normalized RMSE is greater than 30%.

An index of agreement (D) will also be used and indicated as follow.

$$D = 1 - [\frac{\sum_{i=1}^{n}(Pi-Oi)^2}{\sum_{i=0}^{n}(|Pi-O|)+(|oi-O|)^2}] \quad 0<d<1$$ ….............. 3

Where D is index of agreement and Oi and Pi are observed and predicted values, respectively for the ith data pair, O is mean of observed.

Climate data for the target locations

Simulation of climate change impact and adaptation required future climate data to modify the observed weather data. In order to investigate the response of sorghum production under the future climate condition daily weather variables such as rainfall, maximum temperature, minimum temperature and solar radiation were obtained from the WorldClim baseline climate data (1980-2009), and the 17 CMIP5 GCM out-puts run under RCP 4.5 and RCP 8.5 for 2030 s and 2050s time slice were downloaded for the target sites from CIAT's climate change portal (http://ccafs-climate.org/) and downscaled to the target site using Markism GCM. The Global Climate Models (GCMs) used to assess impact of projected climate change and crop management option for sorghum include: BCC- CSM 1.1 [25], BCC-CSM 1.1(m) [25], CSIRO-Mk3.6.0 [26], FIO- ESM [27], GFDL-CM3 (Donner,2011), GFDL-ESM2G (Dunne, 2012), GFDL-ESM2 M (Dunne, 2012),GISS-E2-H [28], GISS-E2-R [28], HadGEM2-ES(Collins, 2011), IPSL-CM5A-LR (Dufresne et al., 2013),IPSL-CM5A-MR (Dufresne, 2013), MIROC-ESM [29], MIROC-ESM-CHEM [29], MIROC5 [30], MRI-CGCM3 [31] and NorESM1-M.

Global climate models (GCMs) and downscaling to the study site

For each location, Mark Sim employs a climate record. A climate record comprises the latitude, longitude, and elevation of the site along with monthly rainfall, daily average temperature, and daily average diurnal temperature variation. The temporal phase angle measures how much the meteorological data is "rotated" over time. This rotation removes timing differences in climate events, such as the seasons in the northern and southern hemispheres, so that standardized climate data may be analyzed. The climate data is converted to a standard date using the 12-point fast Fourier transform based on the first phase angle, which is calculated using rainfall and temperature [22]. In Mark Sim, almost all operations are performed in rotating date space. The World Clim V1.3 climate database is used to interpolate the climate at the required location. Most of the information in World Clim may be regarded as representative of the current climate. It uses a variety of historical meteorological data sources. World Clim performs thin plate smoothing with a predetermined lapse rate using the ANUSPLIN program. Bicubic interpolation is used over a kernel of the next sixteen GCM cells on a 1x1° grid of GCM differentials. The values for each RCP regime or year are obtained by computing them using polynomials fitted to each GCM result. The ensemble, which in this case comprises of 17 GCMs, is calculated using the polynomial coefficients for each GCM. The predicted GCM differential values are added to the rotating record. This illustrates unintelligent downscaling [32] to the monthly climatic readings. Next, MarkSim is used to simulate the daily weather sequences using stochastic downscaling.

Climate change scenarios used in the Study

Two climate change scenarios (RCP4.5 and RCP8.5) were used to assess climate change impact and to evaluate management option. The baseline scenario (1980-2010) was used for comparison. 380 ppm of CO_2 was used for the baseline scenario whereas 423 and 432 ppm were used for RCP 4.5 and RCP 8.5, respectively for 2030s and 499 and 571 ppm of CO_2 were used for RCP 4.5 and RCP8.5, respectively for the 2050s. RCP's are greenhouse gas concentration trajectories adopted by the IPCC for its fifth assessment. These scenarios are briefly described as follows. In RCP4.5 scenario, GHGs concentrations rise with increasing speed until the forcing is 4.5 W m^{-2} in the year 2100. This is a moderate emission scenario of concentration rise. In RCP8.5, GHGs concentrations rise with increasing speed until the forcing is 8 W m^{-2} in the year 2100. This is a high scenario of concentration rise.

Simulating sorghum productivity under projected climate changes

The simulation research employed the CERES-sorghum model in conjunction with the seasonal analysis tool included in DSSAT V4.7. The findings of several climate change scenarios were used to modify the starting weather (temperature and rainfall) and CO2 conditions inside the DSSAT model in order to examine the sensitivity of sorghum production in future climates. The crop model was fed daily climatic data, which included maximum and minimum temperatures, solar radiation, rainfall, and CO2 growth relative to the baseline climate. The test variety was a previously calibrated cultivar (Girana-1). Both the baseline climate (1980–2009) and the anticipated climatic shifts in the 2030s and 2050s were included in the simulations. The baseline CO2 concentration was 380 ppm, whereas scenarios RCP4.5 and RCP8.5 employed CO2 concentrations of 423 ppm and 432 ppm, respectively, in the 2030s and 449 ppm and 571 ppm in the 2050s. The soil profile was taken into consideration at the maximum amount of soil water available on July 12, the day the simulation began. In the model, the crop was produced with rainwater. An ensemble of 17 GCMs' climatic data was used to predict crop response to future climate projections. Using standard management and soil conditions, the crop model was run for both the base climate and the future climates for each climate change scenario. Days to anthesis, days to physiological maturity, leaf area index, biomass, and grain yield were among the calculated characteristics of the model output that were noted. The following comparison was made between the cultivar's production and associated treats under the baseline and future climates:

$$\text{change yield}(\%) = \frac{\text{Y Perdicted} - \text{Y base}}{\text{Y base}} * 100 \ldots \ldots 4$$

Where, Y is yield of the crop

Crop management scenario used in the study

Supplemental irrigation as a management strategy and cultivars of various maturity groups as genetic choices were used to assess the potential for increasing the benefits of sorghum grain output. From the baseline cultivar (Girana-1), which was calibrated for the conditions in northeastern Ethiopia, virtual cultivars containing different plant features were created. Three age classes of sorghum cultivars were taken into consideration in order to create these virtual cultivars: 15% shorter maturity, 15% longer maturity, and baseline (no change). Genetic coefficients determining seedling emergence to the end of the juvenile phase (P1), phasic development leading to panicle initiation (P2R), thermal time from the end of flag leaf expansion to anthesis (PANTH), and the interval between successive leaf tip appearances (PHINT) were all reduced by 15% in order to shorten the crop maturity. Each of those parameters was raised by 15% in order to create the cultivar with a prolonged maturity. Following their designation, the cultivars were LMC (long maturing cultivar), SC (standard cultivar), and SMC (short maturing cultivar). The simulations were run for several cultivar combinations with and without additional watering. Three applications of the supplementary irrigation—henceforth referred to as (SI)—were made throughout the crop's booting, heading, and early grain filling phases. Every irrigation application received the same volume of water (75 mm). When the available soil moisture in the crop rooting depth exceeds 50% of its field capacity, further irrigation water is presumably administered. In order to restore the soil water content in the rooting depth to its field capacity level, the appropriate quantity of water has to be administered.

Data analysis

Genstat 18thedn was used to do an analysis of variance (ANOVA) on all simulation output data. The Least Significant Test (LSD) was used to differentiate software and means at the 5% probability level. Because the sorghum yield in one year under a particular treatment was unaffected by another year (previous year carry-over of soil water was not simulated), simulation years were regarded as replications (blocks).

Since the meteorological parameters of the simulated years in this research were unexpected, rigorous randomization of the simulation years (blocks) was not required.

RESULTS AND DISCUSSIONS

Model calibration

Eleven eco-physiological coefficients are used in the CERES-Sorghum model to simulate phenology, growth, yield, and yield components. Table 1 provides an explanation of each genetic coefficient. The thermal time from the start of grain filling and physiological maturity (P5) was 490, and the thermal

Table 1: Description of the genetic coefficient of cultivar Girana-1 within the DSSAT model.

Symbol	Definition
P1	Thermal time from seedling emergence to the end of the juvenile phase (°C.d)
P2	Thermal time from the end of the juvenile stage to tassel initiation (°C.d)
P2O	Critical photoperiod or the longest day length (in hours)
P2R	Phasic development leading to panicle initiation (°C.d)
PANTH	Thermal time from the end of tassel initiation to anthesis (°C.d)
P3	Thermal time from to end of flag leaf expansion to anthesis (°C.d)
P4	Thermal time from anthesis to beginning grain filling (°C.d)
P5	Thermal time from beginning of grain filling to physiological maturity (°C.d)
PHINT	The interval in thermal time between successive leaf tip appearances (°C.d)
G1	Scaler for relative leaf size
G2	Scaler for partitioning of assimilates to the panicle (head)

Table 2: Calibrated genetic coefficients of the cultivar Girana-1 at Sirinka, north eastern Ethiopia.

Genotype	P1	P2	P2O	P2R	PANTH	P3	P4	P5	PHINT	G1	G2
Girana-1	420	102	13	90	400.5	152.5	81.5	490	49	10	4

Table 3: Comparison of simulated and observed days to anthesis, days to maturity, grain yield and above ground biomass yield of sorghum cultivar Girana-1 at Sirinka, northeastern Ethiopia.

Parameters	Observed	Simulated	R^2	d-stat	RMSE	nRMSE (%)
Days to anthesis	73	75	0.78	0.87	2	2.74
Days to maturity	125	127	0.94	0.92	2	1.6
Grain yield	3562	3084	0.89	0.9	478	13.42
Biomass yield (kg ha^{-1})	15420	14508	0.87	0.88	912	5.91

Table 4: Comparison of simulated and observed days to anthesis, days to maturity, grain yield and above ground biomass yield of sorghum cultivar Girana -1 at Sirinka, north-eastern Ethiopia.

Parameters	Observed	Simulated	R^2	d-stat	RMSE	nRMSE (%)
Days to anthesis	71	73	0.78	0.87	1.83	2.6
Days to maturity	122	125	0.99	0.91	3.3	2.7
Grain yield	2932	2351	0.94	0.67	685.6	23.4
Biomass yield (kg ha^{-1})	11656	11365	0.98	0.98	477.8	4.1

time from seedling emergence to the end of the juvenile phase was 420 (Table 2). The genetic coefficients determined in the CERES-Sorghum model to characterize the growth and development of the cultivar are presented in Table 2. The RMSE for anthesis, physiological maturity, grain yield and above ground biomass yield were 2, 2, 478 and 912, respectively whereas the Normalized Root Mean Square Error CV(%) for the respective parameters were 2.74, 1.6, 13.42 and 5.91 (Table 3). The results showed that the cultivar specific parameters (genetic coefficients) within the model were reasonably adjusted.

Model evaluation

According to the simulation results, the goodness fits (R2) were 78% for anthesis, 99% for physiological maturity, 98% for aboveground biomass yield, and 94% for grain yield. The d-statistics value was 0.87 for anthesis, 0.91 for physiological maturity, 0.67 for grain yield, and 0.98 for aboveground biomass yield. Table 4 shows that the nRMSE was 2.6% for anthesis, 2.7% for physiological maturity, 23.4% for grain yield, and 4.1 for above-ground biomass output. The effectiveness of the CERES-Sorghum model in DSSAT to simulate phenology, growth, and yield of sorghum in the semi-arid environment of northeastern Ethiopia was shown by the high agreement between the simulated and observed data.

Projected climate Change in the study site

The result showed that both maximum and minimum temperatures are predicted to increase in the semi-arid environment of northeastern Ethiopia both in 2030s and 2050s under both climate change scenarios (Table 5). Based on the result, mean maximum temperature is projected to increase by 1.4°C and
1.9°C by 2030s and 2050s time periods, respectively under RCP
4.5 scenario and by 1.5°C and 2.5°C by 2030s and 2050s time slice respectively under RCP 8.5 scenario. Regarding rainfall, it is predicted to increase by 1.5% and 4.5% in 2030s and 2050s, respectively under RCP 4.5 scenario and increase by 3.7 and 3.2% in 2030s and 2050s, respectively under RCP 8.5 scenario. The result of this study is in line with Conway and Schipper [33], Setegn *et al.,* [34] and Dereje *et al.,*[35] who reported an increase in temperature in the coming decades in Ethiopia. Since crop yield is the results of the combination of environmental factors such as rainfall, temperature and solar radiations, so the variation in these climate parameters in the future could affect sorghum production in semi-arid environments of northeastern Ethiopia. **Table 5:** Change in annual rainfall (%) and temperature in 2030s and 2050s as compared to baseline period (1980-2009) at Sirinka, northeastern Ethiopia.

Time periods	Rainfall (%)		Maximum temperature (°C)		Minimum temperature (°C)	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
2030s	1.5	3.7	1.4	1.5	1.4	1.7
2050s	4.5	3.2	1.9	2.5	2	2.7

Table 6: Grain yield of sorghum cultivars under baseline, 2030s and 2050s time periods at Sirinka, northeastern Ethiopia.

	Simulated grain yield (kg ha^{-1})				
Cultivars	RCP 4.5		RCP 8.5		
	2030s	2050s	2030s	2050s	Baseline
SC	2938	3081	2950	3335	2441
SMC	2939	2913	2867	3012	2789
LMC	2811	3063	2828	3374	2099
GM	2896	3019	2882	3240	2443
CV (%)	16.6	16.5	16.2	13.2	18.9
LSD (P=5%)	248.8	257.2	241.2	220.3	238.5

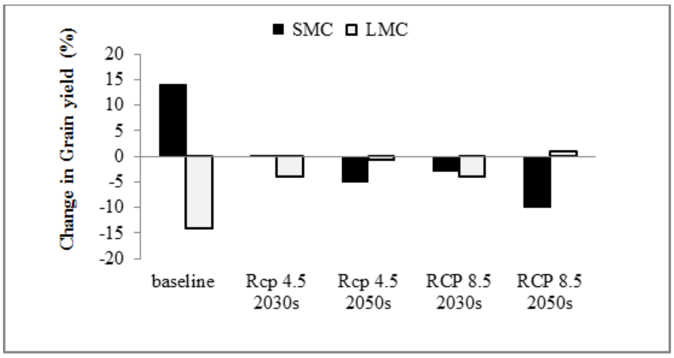
SC=Standard cultivar, SMC=Short maturing cultivar, LMC=Long maturing cultivar, GM= Grand mean, CV=Coefficient of variation, LSD=Least significance difference

Grain yield of sorghum cultivars under projected climate changes

According to the simulation findings, cultivars' grain yields fluctuated considerably across the baseline, 2030s, and 2050s time periods (Table 6). Under the baseline climate, the short-maturing cultivar produced more grain than the long-maturing cultivar. However, in both scenarios, it is anticipated that the short maturing cultivar's grain output would decline in the 2030s and 2050s. In comparison to the grain production of the short maturing cultivar, the long maturing cultivar is also expected to rise by around 5% and 12% in the 2030s and 2050s, respectively, under the RCP 8.5 scenario. Increased rainfall relative to the baseline era may be linked to the long-maturing cultivar's better grain output in future climates. Ademet al. and Piara et al. [36] claim that the long-maturing cultivar will benefit more from the future climate's increased rainfall. According to Msongaleli et al. [37], longer cultivar growing times in the field led to higher yields. By lowering the terminal moisture stress, the long-maturing cultivar may express its genetic potential. It is anticipated that the short-maturing cultivar's grain production would decline relative to the long-maturing cultivar by the 2050s. Elevated temperatures have the potential to impact crops by accelerating their growth and development phases and shortening their life cycle. Therefore, compared to long-maturing cultivars, short-maturing cultivars may be more impacted by the greater temperature influence on their growth and development phases. Maintaining photosynthetic capacity during the grain-filling period has been directly linked to higher grain yield in sorghum genotypes. Borrellet al., [38] and Sultan et al., [39] also reported that traditional millet and sorghum cultivars that are sensitive to photoperiod and have been used for centuries by local farmers may be more resilient to future climate conditions than contemporary cultivars bred for their high yield potential (Figure 1).

Response of sorghum cultivars to supplemental irrigation under projected climate change

The combined effect of different maturity group of sorghum cultivars and application of supplemental irrigation were evaluated on grain yield of sorghum in the baseline, 2030s and 2050s time periods under RCP 4.5 and RCP 8.5 scenarios. According to the simulation results, mean grain yield of the standard, short and



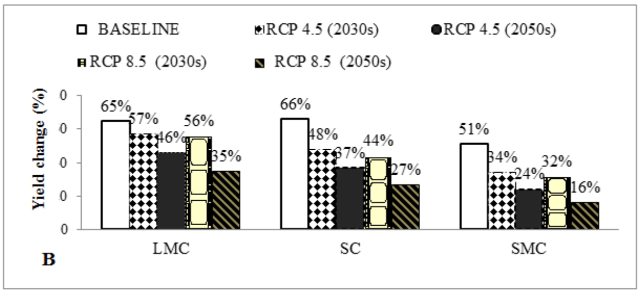
Note:-LMC and SMC stand for long maturing cultivar and short maturing cultivar respectively.

Figure 1: Change in grain yield (%) of short and long maturing cultivars as compared to the standard cultivar at Sirinka, north eastern Ethiopia.

According to the baseline climatic scenario, long-maturing cultivars under supplementary irrigation conditions are expected to grow by around 66%, 51%, and 65%, respectively. In comparison to grain yield from those cultivars under rainfed conditions, the simulation result also showed that the mean grain yield of the standard, short maturing, and long maturing cultivars under supplemental irrigation is expected to increase by approximately 48%, 34%, and 57% in the 2030s under the RCP 4.5 scenario and by approximately 37%, 24%, and 46% in the 2050s under the same scenario. The results also showed that, in comparison to rainfed conditions, the mean grain yield of standard, short-maturing, and long-maturing cultivars under supplemental irrigation is expected to increase by roughly 44%, 32%, and 56% in the 2030s under the RCP 8.5 scenario and by 27%, 16%, and 35% in the 2050s under the RCP 8.5 scenario, respectively (Figure 2).

CONCLUSION

The findings of the CERES-sorghum model's calibration and assessment in a semi-arid region of northeastern Ethiopia demonstrated that the simulated growth, development, and yield of sorghum were in excellent agreement with the corresponding actual values. The growth, development, and yield of sorghum were effectively simulated using the CERES-sorghum model. It may be concluded that the model can be used to prioritize different crop management strategies and estimate potential benefits provided it is calibrated correctly.



SC=standard cultivar, SMC= short maturing cultivar, LMC= long maturing cultivar, RF= rainfall, SI= supplemental irrigation

Figure 2: Change in grain yield (%) of different maturity group of sorghum cultivars in response to supplemental irrigation as compared to rained grain yield in the baseline, 2030s and 2050s under RCP4.5 and RCP8.5 climate change scenarios at Sirinka, northeastern Ethiopia.

choices either separately or in combination. As a result, the CERES-sorghum model may be used as a tool to evaluate management strategies and predict the effects of various climate change scenarios. Climate change is a major global environmental, social, and economic concern, especially in low-latitude nations. Due to its heavy dependence on a climate-sensitive economy (agricultural), Ethiopia is one of the most susceptible nations in Sub-Saharan Africa (SSA). Therefore, it is imperative to take immediate action to mitigate the effects of climate change. Site-specific research might do this. In light of this, this research was carried out in semi-arid northeastern Ethiopia to forecast the effects of anticipated climate change and assess variety differences as a management option for future climate change.Grain yield of sorghum cultivars fluctuated dramatically between the baseline period, the 2030s, and the 2050s, according to the findings of the current CERES-Sorghum simulation research. Under the baseline climate, the short-maturing cultivar produced more grain than the long-maturing cultivar. However, in both scenarios, it is anticipated that the short maturing cultivar's grain output would decline in the 2030s and 2050s. In comparison to the grain production of the short maturing cultivar, the long maturing cultivar is also expected to rise by around 5% and 12% in the 2030s and 2050s, respectively, under the RCP 8.5 scenario. Increased rainfall relative to the baseline era may be linked to the long-maturing cultivar's better grain output in future climates. High temperatures may have an impact on crops by shortening their life cycle and accelerating their development and growth phases. Therefore, compared to long-maturing cultivars, short-maturing cultivars may be more impacted by the greater temperature influence on their growth and development phases.

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