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Research Article

Simulation Study on Climate Change Impact and Management Options for Sorghum [Sorghum bicolor (L.) Moench] Production in the Semi-Arid Northeastern Ethiopia

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ABSTRACT

Climate change is one of the current issues that severely influence all climate sensitive sectors like agriculture. Crop management options are needed to minimize the impact and sustain regional food production.The objectives of this study were (1) to calibrate and evaluate the CERES-Sorghum Model of DSSAT (V4.7) for simulating phenology, growth and yield of sorghum (2) to assess projected climate changes (2030s and 2050s) in the study area (3) to simulate impact of projected climate change on phenology, above ground biomass and grain yield of sorghum (4) to explore the possibility of employing supplemental irrigation and sorghum cultivars as management options. The CERES-sorghum model in DSSAT (V4.7) was first calibrated and evaluatedfor sorghum cultivarGirana-1 using experimental data. Daily weather variables (1980–2009) that include rainfall, maximum temperature, minimum temperature and solar radiation) were obtained from the nearest weather station at Sirinka, Ethiopia. The 17 CMIP5 GCM out-puts run under RCP 4.5 and RCP 8.5 for 2030 s and 2050 s time slice were downloaded for the target sites from CIAT's climate change portal (http://ccafs-climate.org/) and downscaled to the target sites using Markism GCM. The model calibration result indicated that cultivar specific parameters within the model were reasonably adjusted. The model evaluation result also showed that the model simulated phenology, grain yield and above ground biomass yield with high accuracy with minimum RMSE of 1.83 for anthesis, 3.3 for physiological maturity, 685.6 for grain yield, 477.8 for above ground biomass yield. The analysis of future climate showed thatmean maximum temperature is projected to increase by 1.40C and 1.90C by 2030s and 2050s time periods, respectively under RCP 4.5 and by 1.50C and 2.50C by 2030s and 2050s time slice respectively under RCP 8.5. Rainfall, it is predicted to increase by 1.5% and 4.5% in 2030s and 2050s, respectively under RCP 4.5 and by 3.7 and 3.2 % increase in 2030s and 2050s, respectively under RCP 8.5. Phenology of sorghum is predicted to significantly ($P < 0.05$) decrease in 2030s and 2050s. However, grain yield of sorghum is predicted to significantly ($P < 0.05$) increase in 2030s and 2050s. The simulation result also showed that grain yield of sorghum will be substantially increased using supplemental irrigation and long maturing cultivars in future climate condition.

Keywords: Climate change; Crop model; DSSAT; Supplemental irrigation; RCP; Sorghum

INTRODUCTION

Agriculture is the source of livelihood to majority of the Ethiopian population and is the basis of the national economy, where small-scale subsistence farming is predominant. This sector employs more than 80% of the labor force and accounts for 45% of the GDP and 85% of the export revenue [1]. Ethiopian agriculture is heavily dependent on natural rainfall, with irrigation agriculture accounting for less than 1% of the country's total cultivated land. The amount and temporal distribution of rainfall and other climatic factors during the growing season are critical to crop yields and can induce food shortages and famine.

In the lowlands of Ethiopia, the traditional farming practice relies entirely on a rainfed crop production system, which is characterized by poor crop performance and low yields. The major factors responsible for poor yields include moisture stress, low soil fertility, Strigahermonthica, and the limited access to improved seed and efficient production technologies. The most important factor influencing the productivity of crops in the region is the erratic rainfall patterns [2]. Rainfall is insufficient, uneven in its distribution and unpredictable in its inception [3]. Drought is one of the major challenges affecting crop production worldwide. Climate changes will increase the frequency of droughts, particularly in many countries in Africa that are already drought

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prone. It is predicted that, by 2050, water shortages will affect 67% of the world's population [4]. In the arid and semi-arid tropics, the probability of drought is highest at the start and end of the growing season. Drought stress at the beginning of the growing season severely affects plant establishment, whereas drought stress at the flowering or grain-filling stages may result in reduced establishment, reduced yield or complete crop failure [5].

Climate change due to greenhouse gas emissions is expected to increase temperature and alter precipitation patterns, which put pressure and uncertainty to crop production. Agriculture is the first to be adversely affected by climate variability and change. Crop production in such regions is expected to be adversely affected [6]. The sensitivity, adaptive capacity and degree of exposure make it agricultural production vulnerable to climate impacts [7]. About 89% of cereals in sub-Saharan Africa are rainfed [8] that makes climate a key driver of food security [9]. There is a growing consensus in the scientific literature that over the coming decades, higher temperature and changing precipitation levels caused by climate change will depress crop yields in many countries [10]. This is particularly crucial in low-income countries, where adaptive capacity is perceived to be low [11]. Many African countries, which have economies largely based on weather-sensitive agricultural production, are particularly vulnerable to climate change [10]. The magnitude of climate change impacts depends on the type of crop and growth stage. As crops are phenotypically and genetically different, they respond to changes differently. Agricultural production in arid and semi-arid areas is mostly dominated by a very few cereal crops and hence, is less diversified in crop production. As a result, giving due attention to crops which are importantly grown and produce reasonable yield in such harsh environments is timely indispensable.

Globally, sorghum (Sorghum bicolor (L.) Moench is the fifth most important cereal crop after maize, rice, wheat and [12]. It is a major food security crop in sub-Saharan Africa supporting some 300 million people. It is grown in drought-prone and marginal areas in semi-arid zones where other crops cannot grow reliably. In Ethiopia, sorghum is a major staple food crop, ranking second after maize in total production [13]. It ranks third after wheat and maize in productivity per hectare, and after tef and maize in area cultivated. It is grown in almost all regions, covering a total land area of 1.8 million ha [13].

Assessing the impact of climate variability on sorghum production in different parts of the world can be done through the use of crop and climate scenarios. Use of Climate Models helps in improving predictability of climate behavior on different time scales such as seasonal, annual, decadal, and centennial. Models help to examine the extent to which observed climate variability and change may occur as a result of natural variability, human activity, or both. Results and projections obtained from climate models provide important information that can be used to make informed decisions at national, regional, and local levels.

The previous assessments of climate change impacts on crop production in Ethiopia were either at the national [14] or larger scale such as the East African regional levels [15]. There are only a few studies at subnational or local levels within Ethiopia [16]. Hence, it is necessary understanding impact of climate change on sorghum yields at local scales when considering for planning and designing appropriate management strategies. Very few studies have examined the impact of climate change on sorghum yield at the local scale. Therefore, this study attempted to close this gap by assessing how future temperature and rainfall is likely to change in the future in the study area, establish how these changes affect sorghum production and how adaptation strategy can enhance future sorghum production in the semiarid environment of northeastern Ethiopia.

Advances in computer technology have made possible the consideration of the combined influence of several factors in various interactions. It is possible to quantitatively combine the soil, plant, and climatic systems to more accurately predict crop yield. Modeling is the use of equations or sets of equations to represent the behavior of a system. Models simulate the behavior of real crop by predicting the growth of its components, such as leaves, roots, stems and grains. The DSSAT Model has been used to study soil fertility, water and irrigation managements, yield gap analysis, genotype by environment interaction in plant breeding, climate change and climate variability, risk insurance and adaptive management [17]. Recently, the application of crop modeling technique for assessing impacts of climate change on crops has received major attention, which provided solution in terms of reducing cost and improving knowledge. The DSSAT model has been used worldwide to simulate crop biomass and yield, and soil nitrogen (N dynamics) under different management practices and various climatic conditions [18]. There is continuous need to test and update the models under a wide range of environments and cropping practices [19]. Thus, this study was focused to calibrate and evaluate the CERES-Sorghum model of DSSAT in the study region, predict future climate change in the study area, predict impact of projected climate change on sorghum production and evaluate effect of supplemental irrigation on sorghum productivity as management option in the semiarid environment of northeastern Ethiopia.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted during 2018/2019 main cropping season on research site of Sirinka Agricultural Research Center, which is located in the semi-arid environment of northeastern Ethiopia. The area is situated at an altitude of 1850 meter above sea level (m.a.s.l.) with latitude 11^0 45' 00'' and longitude of 39^0 36'36''. The study area is generally characterized as semi-arid where rainfall is highly erratic, low in amount and uneven in distribution [20]. The area receives annual rainfall of about 945 mm with maximum and minimum temperature of 27.3°C and 13.6°C, respectively. The soil type of the area is Eutric Vertisol.

Experimental procedure

Sorghum cultivar (Girana-1) was sown in spacing of 75 cm*15 cm on plot size of 10 m by 10 m and replicated three times. Recently recommended blended fertilizer (NPS) was applied during planting at the rate of 100 kg ha^{-1} whereas nitrogen fertilizer in the form of urea was applied in split at the rate of 50 kg ha^{-1} i.e. half at planting time and the remaining half at 35 days after the crop emergence. Other crop management practices for the cultivar were applied based on local recommendation. For the evaluation of the model, data on phenology, growth and yield were obtained from Sirinka Agricultural Research Center collected from field experiment in 2013, 2015 and 2017.

Description of the DSSAT model

DSSAT (Decision Support System for Agro-technology Transfer) is one of the most widely used modeling systems across the world. Currently, the DSSAT shell is able to incorporate models of 32 different crops, including several cereal grains, grain legumes, and root crops [21]. Decision Support System for Agro-technology Transfer (DSSAT) is one of the first packages that modified weather simulation generators and it introduced a package to evaluate the performance of models for climate change situations. The models are process-oriented and are designed to work independent of location, season, crop cultivar, and management system. The models simulate the effects of weather, soil water, genotype, and soil and crop nitrogen dynamics on crop growth and yield [22]. DSSAT and its crop simulation models have been used for a wide range of applications, including on-farm and precision management to regional impact assessments of the impact of climate change and variability. As a software package integrating the effects of soil, crop phenotype, weather and management options, DSSAT allows users to ask "what if" questions and simulate results by conducting, in minutes on a desktop computer, experiments which would consume a significant part of an agronomist's career.

Description of the (CERES)-sorghum model

The Crop-Environment-Resource-Synthesis (CERES)-Sorghum model is one of the components of DSSAT model. The major components of the model are vegetative and reproductive development, carbon balance, water balance and nitrogen balance [23]. It simulates sorghum growth and development using a daily time step from sowing to maturity and ultimately predicts yield. Genotypic differences in growth, development and yield of crop cultivars are affected through genetic coefficients (cultivar-specific parameters) that are inputs to the model. The model also simulated physiological processes that describe the crop response to major weather factors, including temperature, precipitation and solar radiation and include the effect of soil characteristics on water availability for crop growth.

Calibration and evaluation of the CERES-sorghum model

The CERES-sorghum model, included in the DSSAT system, version 4.7 was used to simulate growth, development and yield of sorghum. Calibration of model is as an adjustment of some parameters and functions of a model so that predictions are the same or at least very close to the data obtained from the field experiments. In many instances, minor adjustments have to be made for some parameters [24]. The CERES-sorghum model requires genetic coefficients that describe the phenology, growth and yield characteristics for each cultivar. In this study, data for the calibration of the model were generated from field experiment conducted in 2018 on research site of Sirinka Agricultural Research Center which is located in semi-arid northeastern Ethiopia. The crop model was evaluated using phenological and yield data of 2013, 2015 and 2017) obtained from Sirinka Agricultural Research Center. Through the use of a 'Trial and Error' method, the calibration was made by establishing a tiny change (±5%) ofeach parameter. The first step was adjusting of genetic coefficients that determine phenology followed by yield and yield components. The coefficients were used in the subsequent evaluation of the model. The observed dates of anthesis and physiological maturity and yield were statistically compared to the simulated values with the coefficient of determination (R^2), the index of agreement (d) 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).

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

Where N is the number of observed values and Oi and Pi are observed and predicted values, respectively for the i^{th} data pair

$$N\,RMSE = \frac{RMSE}{N} x\ 100 \ldots\ldots 2$$

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.

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

Where D is index of agreement and Oi and Pi are observed and predicted values, respectively for the i^{th} 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 any location, Mark Sim makes use of a climate record. A climate record contains the latitude, longitude and elevation of the location, and monthly values of rainfall, daily average temperature and daily average diurnal temperature variation. It also includes the temporal phase angle, that is, the degree by which the climate record is "rotated" in date. This rotation is done to eliminate timing differences in climate events, such as the seasons in the northern and southern hemispheres, so that analysis can be done on standardized climate data. The climate record is rotated to a standard date, using the 12 point fast Fourier transform, on the basis of the first phase angle calculated using both rainfall and temperature [22]. In Mark Sim, almost all operations are done in rotated date space. The climate database World Clim V1.3 is used to interpolate the climate at the required point. World Clim may be taken to be representative of current climatic conditions (most of the data. It uses historical weather data from a number of databases. World Clim uses thin plate smoothing with a fixed lapse rate employing the program ANUSPLIN. Bicubic interpolation is used over a kernel of the nearest sixteen GCM cells on a 1×1°grid of GCM differentials. These are calculated from polynomials fitted to each GCM result which are used to return the values for any year or RCP regime. The ensemble (of 17 GCMs in this case) is calculated directly from the polynomial coefficients for each GCM. The estimated GCM differential values are added to the rotated record. This is an example of unintelligent downscaling [32] to the monthly climate values. MarkSim then uses stochastic downscaling to simulate the daily weather sequences.

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 CERES-sorghum model coupled with the seasonal analysis program available in DSSAT V4.7 was used for the simulation study. In order to investigate the sensitivity of sorghum production in future climate, initial weather (both temperature and rainfall) and CO_2 conditions within the DSSAT model was modified using the results of different climatic change scenarios. Daily climate data that include: maximum and minimum temperature, solar radiation and rainfall, with reference to the baseline climate, along with CO_2 increase were used as input to the crop model. Previously calibrated cultivar (Girana-1) was used as a test variety. Simulations were carried out under the baseline climate (1980-2009) and under the projected climate changes in 2030s and 2050s. The CO_2 concentration was 380 ppm for the baseline whereas 423 ppm and 432 ppm used for scenario RCP4.5 and RCP8.5, respectively in 2030s, while 449 ppm and 571 ppm of CO_2 were used for the respective RCP scenarios in 2050s. The simulation was started on July 12 and soil profile was considered at the upper limit of soil water availability on that day. The crop was grown under rainfall in the model. Crop response to future climate projection was simulated using ensemble of 17 GCMs climate data. The crop model was run for the base climate and for the future climates under each climate change scenarios using typical management and soil conditions. Calculated attributes of the model output such as days to anthesis, days to physiological maturity; leaf area index, biomass and grain yield were recorded. The change in yield and related treats of the cultivar under the baseline and future climate were compared as follows:

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

Where, Y is yield of the crop

Crop management scenario used in the study

The possibilities for achieving more benefit of sorghum grain yield was tested by using supplemental irrigation as a management option and cultivars of different maturity groups as genetic options. Virtual cultivars incorporating various plant traits were developed from the baseline cultivar (Girana-1) calibrated for the northeast Ethiopian condition. To develop these virtual cultivars, three-maturity groups of sorghum cultivars were considered: Baseline (no change), 15% shorter maturity and 15% longer maturity. To make the crop maturity shorter, 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 decreased by 15% each. To develop the longer maturity cultivar, those coefficients were increased by 15% each. The cultivars after designated were SMC (short maturing cultivar), SC (standard cultivar) and LMC (long maturing cultivar). The simulations were carried out for the different combinations of the cultivars with and without supplemental irrigation application. The supplemental irrigation here after designated as (SI) was applied three times at different growth stages (booting, heading, and early grain filling stages of the crop). Equal amount of water (75mm) was applied at each irrigation application. It was assumed that supplemental irrigation water was applied when the available soil moisture in the crop rooting depth reaches 50% of its field capacity. Hence, the amount of water to be applied was the amount that replenishes the soil water content in the rooting depth back to its field capacity level.

Data analysis

All simulation output data were analyzed using analysis of variance (ANOVA) using Genstat 18thedn. Software and means were separated using Least Significant Test (LSD) at 5% probability level. Simulation years were considered as replications (blocks), as the sorghum yield in one year under a given treatment was not affected by another year (prior year carry-over of soil water was not simulated). In this study, simulation years were unpredictable weather characteristics; therefore, formal randomization of simulation years (blocks) was not needed.

RESULTS AND DISCUSSIONS

Model calibration

The CERES-Sorghum model uses eleven eco-physiological coefficients for the simulation of phenology, growth, yield and yield components. The description of each genetic coefficient is indicated in Table 1. The values of thermal time from beginning of grain filling to 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

The simulation result indicated that the goodness fits (R^2) was 78% for anthesis, 99% for physiological maturity, 98% for aboveground biomass yield and 94% for grain yield while the d-statistics value for anthesis was 0.87, for physiological maturity it was 0.91, for the grain yield it was 0.67 and it was 0.98 for aboveground biomass yield. The nRMSE was 2.6% for anthesis, 2.7% for physiological maturity, 23.4% for grain yield and 4.1 for above ground biomass yield (Table 4). The result showed that there were excellent agreement between the simulated and the observed values which indicated the performance of the CERES-Sorghum model in DSSAT to simulate phenology, growth and yield of sorghum under the semi-arid environment of northeastern Ethiopia.

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

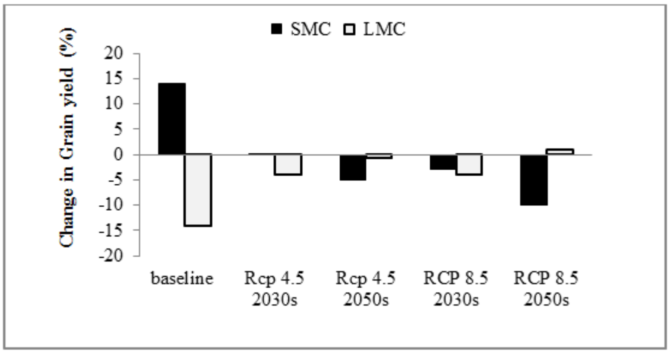
Table 6: Grain yield of sorghum cultivars under baseline, 2030s and 2050s time periods at Sirinka, northeastern Ethiopia.

Cultivars	Simulated grain yield (kg ha^{-1})				
	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

The simulation results showed that grain yield of cultivars significantly varied under the baseline period, 2030s and 2050s time period (Table 6). The short maturing cultivar resulted in higher grain yield than the long maturing cultivar under the baseline climate. However, grain yield of the short maturing cultivar is predicted to decrease in 2030s and 2050s under both scenarios. Grain yield of the long maturing cultivar is also predicted to increase by about 5% and 12% in 2030s and 2050s, respectively under RCP 8.5 scenario as compared to the grain yield of the short maturing cultivar. The higher grain yield of the long maturing cultivar in future climate could be associated to the increase in rainfall as compared to the baseline period. According to Ademet *al.*, and Piara *et al.*, [36] the increase in rainfall future climate will be more beneficial for the long maturing cultivar. Msongaleli *et al.*, [37] reported that increasing the duration of growth of cultivar in the field resulted in increased yields. The long maturing cultivar can express its genetic potential by reducing the terminal moisture stress. By 2050s, grain yield of the short maturing cultivar is predicted to decrease than the long maturing cultivar. High temperature could affect crops by speeding up their development and growth stages and reducing their life cycle. As a result short maturing cultivars could be most affected by the higher temperature effect on their, growth and development stages as compared to long maturing cultivars. Higher grain yield in sorghum genotypes have been directly attributed to maintaining photosynthetic capability during the grain-filling period Borrell*et al.*, [38], Sultan *et al.*, [39] also reported that photoperiod-sensitive traditional cultivars of millet and sorghum that have been used by local farmers for centuries may be more resilient to future climate conditions than modern cultivars breed for their high yield potential (Figure 1).



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

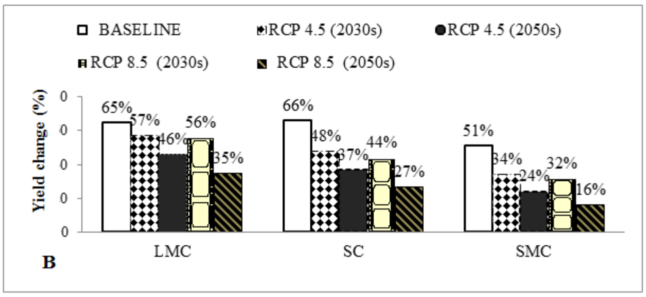
Figure 1: Change in grain yield (%) of short and long maturing cultivars as compared to the standard cultivar at Sirinka, north eastern Ethiopia.

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 long maturing cultivars under supplemental irrigation condition is predicted to increase by about 66%, 51% and 65% under the baseline climate scenario, respectively. The simulation result also indicated that mean grain yield of the standard, short maturing and long maturing cultivars under supplemental irrigation is predicted to increase by about 48%, 34% and 57% in 2030s under RCP 4.5 scenario and by about 37%, 24% and 46% in 2050s time periods under RCP 4.5 scenario for the respective cultivars as compared to grain yield from those cultivars under rainfed conditions. The result also indicated that mean grain yield of standard, short maturing and long maturing cultivars under supplemental irrigation is predicted to increase by about 44%, 32% and 56% in 2030s under RCP 8.5 scenario and by 27%, 16% and 35% in 2050s under RCP 8.5 scenario, respectively, as compared to rainfed condition (Figure 2).

CONCLUSION

The calibration and evaluation results of the CERES-sorghum model on in semi-arid environment of northeastern Ethiopia showed that simulated growth, development and yield of sorghum were in good agreement with their corresponding observed values. The CERES-sorghum model was able to successfully simulate growth, development and yield of sorghum. It can be conclude that if properly calibrated, the model can be used to quantify the possible benefits and prioritization of various crop management



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.

options individually or in combinations. Hence, the CERES-sorghum model can be used as tools to forecast impact of climatic change scenarios and assess management practices.

Climate change is an important environmental, social and economic issue in the world, particularly in low latitude countries. Ethiopia is among the most vulnerable countries in Sub-Saharan Africa (SSA due to its great reliance on climate vulnerable economy (agriculture). Hence, urgent measures that can offset impact of the changing climate are critical. This could be achieved through site-specific studies. In view of this, this study was conducted to predict the impacts of projected climate change and evaluate variety difference as a management option for future climate change in semi-arid northeastern Ethiopia.

The current CERES-Sorghum simulation analysis results showed that grain yield of sorghum cultivars significantly varied under the baseline period, 2030s and 2050s time. The short maturing cultivar resulted in higher grain yield than the long maturing cultivar under the baseline climate. However, grain yield of the short maturing cultivar is predicted to decrease in 2030s and 2050s under both scenarios. Grain yield of the long maturing cultivar is also predicted to increase by about 5% and 12% in 2030s and 2050s, respectively under RCP 8.5 scenario as compared to the grain yield of the short maturing cultivar. The higher grain yield of the long maturing cultivar in future climate could be associated to the increase in rainfall as compared to the baseline period. High temperature could affect cropsby speeding up their development and growth stages and reducing their life cycle. As a result short maturing cultivars could be most affected by the higher temperature effect on their, growth and development stages as compared to long maturing cultivars.

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