Assessment of Climate Change Impact on Sorghum Production in Machakos County

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Abstract. Reduced agricultural production and food security continues to be pressing problems for the larger part of smallholder farmers in Sub-Saharan Africa (SSA), as well as semi-arid Eastern Kenya. The main objective of this study was to assess the potential impacts of climate change on rain-fed sorghum production in the semi-arid environment of Machakos County. The APSIM model was calibrated and evaluated using field experimental data obtained from a two-year experiment (2014 to 2015) of sorghum parameters carried out at Kenya Agricultural and Livestock Research Organization (KALRO) in Katumani. The baseline simulation was based on daily observed climate data for the period 1976 to 2005. The future climate simulations data were derived by perturbing the observed climate data using deltas for the three GCMs and ensemble and were referred to Representative Concentration Pathways (RCPs): RCP 4.5 and RCP 8.5. Each GCMs and the ensemble and the two RCPs were run for three future periods (2010-2039, 2040-2069 and 2070-2099), thus 24 future simulations were run and compared to baseline simulations. Impact of climate change is projected to be more on sorghum under RCP8.5 than RCP4.5. Across all the GCMs projected mean changes on phenological dates (days to 50% flowering and physiological maturity) showed a consistent decline for both sorghum varieties during the long and short growing seasons with the application of different rates of fertilizer. These trends were more manifested in the RCP8.5 than RCP4.5 and in the end century (2071-2100) of the simulation. With the RCP8.5 flowering dates reduced by 24 and 28 days and the crop cycle duration shrunk by 35 and 38 days in the end century (2071-2100) for gadam and seredo, respectively. There was slight increase or decrease in biomass for both varieties under climate change with no fertilizer application. However, with application of 50kg ha^{-1} N, there was a slight increase of biomass. It has been noted that under changing climate sorghum grain yields will constantly increase for both cultivars over the three future time periods with almost 85.3% increase as we approach the end of the century (2070-2099). The extent of yield change was higher for seredo than for gadam. APSIM model was capable of simulating the response of sorghum to climate change and, on the basis of the results obtained; some adaptation strategies could be proposed, such as: modifications of sowing dates or plant populations.

Introduction

High levels of atmospheric gases within the atmosphere, caused by both natural and anthropogenic causes (human activities), are the primary driver of the changing climate being experienced in most regions of the world [1]. It is predicted that these changes would have both negative and positive impacts on diverse economic sectors of any country. These sectors include agriculture, tourism, energy, water resources, forestry, fisheries, and health [2, 3] However, due to the size and sensitivity of the agriculture sector across the world, it is largely affected by the impacts of climate change [4, 5]. In Africa the extent of damage on agriculture is dependent on future scenarios of climate change, the type and amount of farm inputs used for crop production [6, 5].

Major impacts of climate change on agriculture are consequences of temperature increase, changes in rainfall patterns and increase in the levels of CO₂ within the atmosphere. Previous researches have shown no significant increase in the yield of sorghum with the increase of CO₂ [7-9].

In addition to pollen viability and seed setting [10], temperature also affects sorghum yields primarily by influencing the rate at which biomass is accumulated and the crop growth duration [12-14]. Alternatively, rainfall is another dominant factor which controls the yield of sorghum. Extreme water deficits during the flowering period reduce pollination or causes the spikes to dry out, resulting to decreased yields.

The impact of climate change on sorghum prevalence in Machakos County remains unknown owing to the fact that there is uncertainty in the Global Climate Models (GCMs) to predict climate variables especially rainfall. Projections from the GCMs proposes that in future variability in climate is anticipated to increase thus extreme weather events may turn out to be more persistent and severe in the Sub Saharan countries [15-17]. This might lead to food insecurity and also increase exposure of the community to impacts of climate change because of low adaptive capacities. Extreme weather events like floods and droughts, which are triggered by climate variability and climate change, are more frequent in the ASALs of Kenya, making the communities in the ASALs to be at higher risks to variations in climate [18]. These extremes have profound impacts on agriculture, which is the driver of the Kenya's economic growth, contributing approximately 26% of the country's gross domestic product (GDP) and accounting for approximately 65% of the country's total exports [19]. Thus the importance of analyzing the projected impacts of climate change on agricultural production so as to expand on the distress of food security and making sure that repercussions of the impacts are communicated to public and policy makers [20, 3, 21]. This will aid in the formulation of appropriate plans to reduce the impacts of climate change or adapt them.

Despite the large uncertainties of GCMs particularly at local scale due to their coarse resolution [22-24], they have consistently provided credible simulations of climate [25]. The utilization of climate data obtained from GCMs, as input data in most of the crop models, is solitary the most applied approach to this purpose [26, 28-32].

Different types of crop models have been developed and have the ability to reproduce the interactive effects of climate and soil on the yields of any crop in diverse farming systems. They have been gradually used for analyzing climate change impacts on a wide range of crops such as maize [33-38, 40-44] and wheat [45-47, 44, 40]. Such analysis was also carried out for sorghum [48-56, 40, 41, 43].

Agricultural Production Systems sIMulator (APSIM) is one of the crop models and was chosen to simulate sorghum growth and development in this research. This crop model was developed for regions which are semi arid and has been broadly used in smallholder farming systems in the same regions. APSIM has been confirmed to be a helpful tool in examining the probable impacts of climate change on crop production [34, 40, 41, 44, 47, 51]. Prediction of crop yields using crop models has reduced the risk of crop failure in totality or considerably reduced yields since faster results and greater understanding of the crop dynamics can be obtained more quickly.

Hence, the aim of the current study was to calibrate and evaluate APSIM crop model and to use the validated APSIM model to assess climate change impact on sorghum growth and development.

2. Materials and Methods

2.1 Climate and Data Scenarios

Scenarios of climate change for the near-term, mid century and end century (2010-2039, 2040-2069 and 2070-2099) periods were created using three (3) GCMs (GFDL-ESM2M, CanESM2, NorESM1-M) and the ensemble from Coordinated Regional Downscaling Experiment (CORDEX) (Table 1). RCP4.5 and RCP8.5 were employed in the current study to represent high emission and medium stabilization scenarios, respectively. The three CORDEX GCMs were selected owing to their long history of development and evaluation, a preference for finer resolution, and established performance in simulating the climate variables in monsoon regions [57].

RCPs typically refer to the portion of the concentration pathway extending up to 2100, for which Integrated Assessment Models have produced corresponding emission scenarios [39]. RCP8.5 is described by rising amounts of GHGs emissions over time as a result of projections of increased human population of 12 billion by the year 2100, highest rates of urbanization and inadequate rates of technological change [58], hence it is a high emission scenario. RCP4.5 is a medium stabilization scenario in which total radiative forcing is stabilized shortly after 2100 [59-61]. Stabilization is attributed to lower rate of increasing human population as compared to RCP8.5 and intermediary levels of economic growth.

Table 1. Coupled Model Intercomparison Project Phase 5 Global Climate Models used within CORDEX

<i>S/No.</i>	<i>Institute Name</i>	<i>Country</i>	<i>GCM Name</i>	<i>Calendar</i>
1.	Canadian Centre for Climate Modelling and Analysis (CCCma)	Canada	CanESM2	365 days
2.	Norwegian Climate Centre (NCC)	Norway	NorESM1-M	365 days
3.	National Oceanic and Atmospheric Administration-Global Fluid Dynamic Laboratory (NOAA-GFDL)	USA	GFDL-ESM2M	365 days

2.2 APSIM Model Description

Agricultural Production Systems Simulator (APSIM) is a software tool that enables modules to be linked to simulate agricultural systems [62]. APSIM has various modules grouped and categorized as biophysical, environmental or soil, managerial or economic [34]. It simulates the mechanistic growth of crops, soil processes, and range of management options considering cropping systems perspective.

APSIM model was developed for regions which are semi arid and has been broadly used in smallholder farming systems in the same regions. APSIM has been confirmed to be a helpful tool in examining the probable impacts of climate change on crop production [34, 47, 44, 40, 51, 55, 41, 63].

2.3 Data Requirements for APSIM

Before any simulation in APSIM is preceded, the model is first configured by identifying the modules to be applied in the simulation and the sets needed by those modules. As the simulation continues, the modules in APSIM normally need initialization data and temporal data. In general the initialization data is categorized as either generic data (defines the module for all simulations) or precise simulation parameter data for example cultivar, management and site characteristics [62].

Typical site parameters are soil parameters (bulk density, soil particle, drained upper limit (DUL), saturated volumetric water content (SAT), wilting point (LL15), available phosphorus, soil organic carbon, soil pH, soil total nitrogen, effective cation exchange capacity (CEC), exchangeable bases, etc.) for soil modules, daily climate measurements (rainfall, solar radiation, maximum and minimum temperatures) for meteorological modules and management data such as timing of agronomic practices and fertilizer types and amounts and for the management module [34, 62].

2.4 APSIM Model Calibration

The APSIM model was calibrated using the sets of data obtained from detailed field experiment carried out at KALRO, Katumani (1°35'S, 37°14'E, 1600m altitude), Kenya during the MAM and OND seasons for the years 2014 and 2015. In this experiment, two sorghum cultivars (Gadam and Seredo) were planted using spacing of 75 cm × 20 cm and set in a randomized complete block design (RCBD). For optimum growth conditions phosphorus was applied as Diammonium phosphate at sowing, while nitrogen was applied as ammonia nitrate 35 days after

sowing. There were four levels of Nitrogen [0, 50, 75 and 100 Kg N ha^{-1}] and three levels of Phosphorus [0, 50 and 100 Kg P $_2\text{O}_5$ ha $^{-1}$]. The twelve (12) different treatments are presented in Table 2. Calibration of APSIM model for this experiment was done using the climatic conditions, management and soil of the experimental location.

Table 2. Treatments (inorganic fertilizer rates) used in the study

Treatment combination	N (Kg/ha)	P $_2\text{O}_5$ (Kg/ha)	Treatment
N1P1 (Control)	0	0	T1
N2P1	50	0	T2
N3P1	75	0	T3
N4P1	100	0	T4
N1P2	0	50	T5
N2P2	50	50	T6
N3P2	75	50	T7
N4P2	100	50	T8
N1P3	0	100	T9
N2P3	50	100	T10
N3P3	75	100	T11
N4P3	100	100	T12

At the experimental site, the soils are largely sandy clay soils over most of the layers and are classified as Chromic Luvisols (FAO/UNESCO Classification in 1990). Parametrization of the soil modules was performed using data extracted from the field experiments and from correlated literature. Prior to sowing soil samples were obtained at different soil depths (0-15, 15-30, 30-60 and 60-90cm) for analysis of the chemical and physical properties of the soil. Soil input data include , bulk density, soil particle distribution (% of clay,% of sand and % of silt), saturated volumetric water content (SAT), drained upper limit (DUL), wilting point, soil pH, soil organic carbon, soil total nitrogen, available phosphorus, effective cation exchange capacity (CEC), exchangeable bases, etc. The soil data used in the parameterization of the APSIM model is presented in Table 3. Daily weather data (rainfall, solar radiation, maximum and minimum temperature) during the growing seasons were recorded from the agrometeorological station located within the research center.

Table 3. Characteristics of the Chromic-Luvisol Soils at Katumani Research Station in 2014

Soil Depth (cm)	0-15	15-30	30-60	60-90
Particle size distribution (%)				
<i>Sand</i>	68	69	62.5	50.5
<i>Clay</i>	25.3	23.5	31.5	40
<i>Silt</i>	6.7	7.5	6.0	9.5
Bulk Density (g/cc)	1.57	1.57	1.55	1.51
DUL	0.24	0.23	0.30	0.35
Air Dry	0.10	0.11	0.20	0.24
LL15	0.16	0.15	0.20	0.24
SAT	0.24	0.34	0.37	0.38
Sorghum LL	0.16	0.15	0.20	0.27
Soil pH	6.5	6.5	6.2	6.0
Exchangeable Cations (cmol(+)/kg)				
<i>Calcium</i>	3.5	4.1	2.3	2.1
<i>Magnesium</i>	6.6	6.2	6.1	5.9
<i>Sodium</i>	0.3	0.3	0.2	0.2
<i>Pottasium</i>	0.9	0.8	0.7	0.4
% Organic Carbon	0.9	0.8	1.0	0.7
% Total Nitrogen	0.08	0.07	0.06	0.05
Available Phosphorus (mg/kg)				
NO_3^- (kg/ha)	13.44	9.53	10.05	3.93
NH_4^+ (kg/ha)	1.92	0.19	0.40	0.39
Fbiom (0-1)	0.035	0.020	0.015	0.010
Finert (0-1)	0.390	0.470	0.520	0.620

DUL: Drained Upper Limit (Field capacity), Air Dry: Soil moisture content at air dry point, LL15: Lower Limit of water extraction by the crop at 15 bar metric pressure (Wilting Point), SAT: saturated volumetric water content, NH_4^+N : Ammonium nitrogen, NO_3^-N : Nitrate nitrogen, Fbiom: fraction of soil organic matter that is decomposable and originally present in the fast decomposing pool, Finert: fraction of soil carbon which is not vulnerable to decomposition

Calibration of any model is the adjustment of parameters and functions of that model so that the simulations are the same or very close to data obtained from the experimental field. APSIM does not offer any programmed procedures for calibration. So as to calibrate the APSIM model for specific conditions the parameters of the model were changed one at a time, by hand, and quantitative comparisons of model output to observations made. The APSIM model was calibrated using crop growth and development parameters for sorghum. These parameters are the genetic coefficient of the two sorghum cultivars (Gadam and Seredo).

When using a cultivar that is not already calibrated, it is recommended that an existing cultivar that is close to be used. The crop module in APSIM has descriptions of Pioneer_S34 and Texas_RS610 which have parameters very similar to Gadam and Seredo, respectively. Hence parameters of Pioneer_S34 and Texas_RS610 incorporated in APSIM were chosen to describe the Gadam and Seredo varieties, respectively. Soil characteristics used were those typical of soils in Katumani, in Machakos. Initial water content of the soil at sowing was adjusted to 20 % filled from the top. This meant that the top layer of the soil was totally filled with water, then the second layer filled from the top, then the third etc, until all the 20% of the maximum available water was used. This suggested that the top layers of the soil profile were absolutely wet while the bottom layers were dry. The entire soil profile had 20% of the maximum available water. The initial mineral N of the soil profile was set at 48.5 kgha⁻¹ Nitrate (NO_3) and 14.43 kgha⁻¹ Ammonium (NH_4). The sowing rule was set so that sowing took place when there was an accumulation of 20 mm of rainfall within three successive days as per the onset dates criteria. The sowing dates were set to 2nd April 2014 and 20th October 2014 for the MAM and OND seasons, respectively. The seeds were planted at a depth of 30 mm. The row spacing was kept at 0.75m with the plant to plant distance of 0.2m to

give a plant population of 7 plants per m². Nitrogen was applied at 0, 50, 75 and 100 kg Nha⁻¹ at 35 days after sowing (DAS) in the form of Ammonium Nitrate (NH₄NO₃). Traditional land preparation, such as ploughing, was employed.

Surface organic matter, soil water and soil N were reset to original conditions four weeks before the date of sowing of each season so as to remove carry over effects and to let the soil conditions equilibrate with the current weather conditions. This was done to remove most of the bias from the specified initial condition. The parameter *U*, which illustrates the initial phase (when there is adequate water in the soil that is when evaporation rate is constant) of evaporation of water from the soil was set at 6mm day⁻¹, while *Cona*, which characterizes the second phase of soil water evaporation (falling rate of evaporation) was set at 3.5 mm day⁻¹ in the APSIM soil module, these are values accepted in the tropics [64, 34, 65]. SWCON which is a coefficient that indicates the fraction of the water in excess of field capacity that drains to the adjacent layer in a single day was set to 0.7 since the soil is sandy [64, 65]. Phosphorus (P) was assumed to be non-limiting

Data Collection

Sorghum parameters including days to 50% flowering, days to physiological maturity, above ground biomass and grain yield were collected. Days to 50% flowering and physiological maturity were distinguished when 50% of the sorghum plant population for each plot reached each of the two phases. The date of 50% flowering was identified when not less than half of the sorghum plants in the plot showed exposed anthers. Days to 50% flowering were then estimated from the sowing date by subtracting the date of sowing from date of 50% flowering. Physiological maturity was determined by identifying the date of the appearance of a dark (black) layer at the base of the kernel. Days to maturity were then obtained by subtracting the date of sowing from date of physiological maturity.

At harvest, above-ground biomass and grain yield were calculated. Sorghum grain yield was determined by harvesting panicles in all the plots from an area 3m by 3m and threshing was done to separate the grains from the panicles. The grain sub-samples for each cultivar and replicate were then dried in an oven at 70°C for 2 days (48 hours) until a constant weight was attained and the dry weights measurements taken and their weight recorded. Dried weight of the grains was used to estimate the dry weight from the area harvested which was subsequently expressed as Kg/ha. The biomass was also harvested by cutting some sorghum plants just immediately above the ground surface and the fresh weight recorded. Sub-samples from each cultivar and replicate were then dried in oven at 70°C until a steady weight was reached. Above-ground biomass in Kg/ha was then determined as for sorghum grain yield.

2.5 APSIM Model Evaluation

After model configuration with the required input data, the APSIM model was run and simulated days to 50% flowering, days to maturity, total above ground biomass and yield were quantitatively compared to measured (observed) values. Performance of the calibrated model was evaluated by different statistical indices viz., modified index of agreement (*d_m*), coefficient of determination (*r*²) and root mean square error (RMSE) and calculated as per [66-68].

2.6 Impact Assessment

Crop models have been used extensively in the study of climate change impacts on the growth and yield of crops. They may involve direct and indirect (use of weather generators to process data) application of outputs from climate model as input to run the crop simulation models [69]. However, in a few cases, observed climate data may be perturbed using the outputs from climate model [69, 70] thus generating climate change scenarios. In this present study, three climate scenarios (2010-2039, 2040-2069 and 2070-2099) for three GCMs (CanESM2, GFDL-ESM2M, NorESM1-M) and ensemble and for the RCP 4.5 and RCP 8.5 were generated by perturbing the observed climate data for Katumani meteorological station through use the deltas (mean changes) of selected solar radiation, temperature and rainfall. The delta method exacts a change factor from the

projected future climates covering the GCMs onto the hindcast climate data and generates distributions that exhibit the expected variations from the baseline period (1976-2005) in the GCM.

Considering the typical management practices by smallholder farmers' row spacing was kept at 0.75m with the plant to plant distance of 0.2m to give a population density of 7 plants per m² [71]. Low dosage of nitrogen in the form of Ammonium Nitrate (NH₄NO₃) was set at 0 and 50 kg Nha⁻¹. The simulations were run using fixed atmospheric CO₂ concentration of 350 ppm for both the baseline and future period (sorghum is not parameterized for CO₂ levels other than a default of 350 ppm). This could be attributed to the fact that previous studies on impact of CO₂ fertilization in sorghum showed insignificant increase in sorghum yield with increase in CO₂ as it is already saturated with CO₂ [7-9].

To assess the impacts on phenology, growth and yield, the simulated results on phenology, growth and yield were assembled and deviations of the parameters from baseline values were calculated. These deviations were determined for each cultivar, GCM and RCP.

3.0 Results and Discussion

3.1 Environmental Conditions

Temperatures patterns during the long rainfall growing period, April to August 2014 (2015) were fairly similar, with the average maximum and minimum temperatures of 24.5°C (24.8°C) and 13.6°C (14.2°C), respectively compared to mean maximum and minimum temperature of 24.0°C and 12.8 °C for the long term average (1981 to 2012). In both years, both average maximum and minimum temperature were slightly above long-term average. The average of both maximum and minimum temperatures for the short rainfall growing period October to February 2014 (2015) were 27.0°C (26.0°C) and 14.7°C (15.1°C), respectively compared to mean maximum and minimum and of 26.0°C and 14.0°C for the long term average. Optimal temperature range for sorghum at vegetative phase is between 26 to 34°C [73] and that during the reproductive phase is between 25 to 28°C [10]. The observed temperatures during the growing season were slightly outside and within the optimum ranges during the vegetative phase and reproductive phase for March to August growing season. Therefore sorghum could have relatively performed well in the area of study during the March to August growing season. However, the temperatures were within the optimum ranges during the October to February growing seasons as suggested by [72,10], hence sorghum could perform better in the area of study during these seasons compared to the March to August growing seasons. Increase in temperature beyond the optimum range result to withering of the sorghum plants as a result of the scorching effect of the sun.

The least solar radiation (17.1 and 16.1 MJm⁻²day⁻¹) for the long rainfall growing period 2014 and 2015 was recorded in the month of June with the highest solar radiation (19.1 and 19.2 MJm⁻²day⁻¹) occurring in August, respectively. The least (maximum) value of solar radiation in June (August) corresponds to the periods of attainment of flowering (Maturity), hence low (high) evaporation demands is necessary for the crop to attain maximum yields. Decreasing values of solar radiation from planting to flowering allows for little evaporation to take place, thus preventing the issue of water stress during this critical period. Conversely, increasing solar radiation trends from flowering to maturity allows for rapid evaporation thus the grain sorghum ripens quickly. The least solar radiation (18.5 and 17.9 MJm⁻²day⁻¹) for the April to August growing season 2014 and 2015 was recorded in the months of November/December with the highest solar radiation (22.6 and 21.5 MJm⁻²day⁻¹) occurring in February, respectively.

In disparity to the comparable temperature patterns, distribution of rainfall was different during the two years. The total rainfall for long rainfall growing period (April to August), during 2014 and 2015 were 114.4mm 143.2mm, respectively. These rainfall amounts were below the long-term average (1981 to 2012) of 207.1mm. The months that corresponded to the time of planting until flowering during the growing seasons of April to August 2014 and 2015 accumulated rainfall amounting to 69mm and 136.6mm, respectively. The rainfall amounts were approximately 65.1% and 31% below the long term mean respectively in 2014 and 2015. The rainfall amounts during

2015 were seen to be favorable for better sorghum growth since the crop water requirement increases during the reproductive phase. The total rainfall in the month of August for 2014 and 2015 were 458.6 % greater and 79.3% less than the long-term mean. Too much rainfall received in August 2014 resulted in adverse effects on sorghum growth and development and hence reduced the grain quality. This attributed to the lower yields attained during the long rainfall growing period in 2014 as compared to 2015.

The total rainfall for the short rainfall growing period (October to February) 2014 and 2015 was 246.1mm 563.7mm, respectively. The long term mean (1981 to 2012) was found to be 425.4mm. In 2014 short rainfall growing period, rainfall amount recorded was below the long-term mean. During the short rains of 2015, total rainfall was higher than the long-term mean, and approximately 317.6 mm additional rain was recorded in 2014.

From planting to flowering, the rainfall amount received in 2014 and 2015 was 175.7mm and 507.7mm, respectively, in comparison to the long term mean of 290.1mm. Water requirement for sorghum growth and development increases from planting to flowering and thereafter the water requirements decreases during grain filling until the crop matures [85]. Hence, the higher amounts of rainfall received during October to December in 2015 contributed to higher yields compared to 2014. The relatively higher amounts of rainfall (68.9mm) received in February 2014 during the short rainfall growing period could have resulted in poor yields since that month corresponded to the month of harvesting. Heavy rainfall during harvesting is known to affect the grain quality

Generally rainfall distribution for the two seasons in 2014 and 2015 signify the ongoing rainfall variability which strongly influences growth and development of sorghum and thus led to the variability in the sorghum yield that were obtained from the four experimental seasons.

3.2 Model Calibration and Validation

Results of APSIM model calibrations and the genetic coefficients derived from the two sorghum cultivars are presented in Table 4. Statistical indices of APSIM model performance are displayed in Tables 5 and 6. As demonstrated in Tables 5 and 6, RMSE values are low for all the sorghum parameters studied, because the simulated values are in agreement with the observed values. Lesser values of RMSE imply that the model is in a better position in explaining the majority of the variations in the dataset.

In addition, results point out that the simulated days to 50% flowering and maturity for the gadam cultivar reasonably matched the corresponding observed values, owing to the modified index of agreement (dm) of 0.5 and above for both the long and short growing seasons. Nonetheless, the variation in seredo simulations represent some level of error as shown by very low values of modified index of agreement (dm) in both the long and short growing seasons. The dm values approaching one (1) are considered better simulations. Higher values of modified index of agreement showed more precise simulation of sorghum biomass and grain yield. The values were greater than or equal to 0.5 (Table 5 and 6).

The observed and simulated sorghum parameters for both cultivars during the long and short growing seasons depicted good correlation with r^2 values ranging between 45 % and 99% (Table 5 and 6).

Results point out that APSIM has a propensity to somewhat over estimate the phenological parameters, growth and grain yield. Nevertheless, the error in all the parameters was below 15%, which is judged acceptable [73]. Therefore these slight deviations in APSIM will not affect the final trends obtained as much as climate change impact and adaptation studies are concerned. The results obtained here showed that genetic coefficients estimated for each cultivar were robust and once a model is calibrated for a cultivar, it can with high degree of accuracy simulate growth and yield. The calibrated model was used to simulate sorghum growth and development under three scenarios of climate change (near-term, mid-century and end-century).

Table 4. Genetic coefficients used for modeling the two Sorghum cultivars in APSIM

Parameter		Source	Units	Gadam	Seredo
Thermal time accumulation	End of juvenile phase to panicle initiation	C	°C day	100	125
	Flag stage to flowering	C	°C day	100	100
	Flowering to start of grain filling	C	°C day	30	80
	Flowering to maturity	C	°C day	761	695
	Maturity to seed ripening	L	°C day	1	1
Photoperiod	Day length photoperiod to inhibit flowering	D	Hours	12.3	11.5
	Day length photoperiod for insensitivity	D	Hours	14.6	13.5
	Base temperature	L	°C day	8	8

Note. C: calibrated; D: Default; L: literature

Table 5. Statistical Indicators of APSIM Model Performance during the Long Rains

Parameter/Cultivars	Gadam			Seredo		
	RMSE	dm	R ² (%)	RMSE	dm	R ² (%)
Days to 50% flowering	1.2	0.5	45.0	1.6	0.4	50.0
Days to Maturity	2.4	0.6	76.2	2.9	0.4	43.3
Biomass	347.6	0.5	87.9	360.7	0.5	48.1
Yield	52.3	0.6	56.0	227.7	0.5	81.0

RMSE: root mean square error, d_m : modified index of agreement and R^2 : coefficient of determination

Table 6. Statistical Indicators of APSIM Model Performance during the Short Rains

Parameter/Cultivars	Gadam			Seredo		
	RMSE	dm	R ² (%)	RMSE	dm	R ² (%)
Days to 50% flowering	1.0	0.5	99.0	1.3	0.4	53.3
Days to Maturity	1.0	0.8	85.9	1.2	0.4	47.3
Biomass	369.6	0.5	69.0	427.2	0.6	78.4
Yield	155.9	0.6	96.0	196.3	0.8	87.6

RMSE: root mean square error, d_m : modified index of agreement and R^2 : coefficient of determination

3.3 Future Climatic Trends

The GCMs consistently projected increased temperatures (warmer future) for the three future time periods under the two RCPs with a mean temperature increase ranging between +0.8°C and 3.8°C (Table 7). The results agree with the findings by [39, 43] who predicted increases in temperature in most climate change scenarios. The projected maximum and minimum temperature changes depicted strong uniformity with an increasing trend across all the GCMs within the two RCPs. Similar findings were reported by [43] in central Tanzania.

All the GCMs considered show increase in precipitation (wetter future) in the three future periods under the two RCP4.5 and RCP8.5 as compared to the current baseline period. Projected mean rainfall changes across all the GCMs under the two RCPs were 8.2%, though varying considerably across GCMs. The mean projected rainfall change was 6.6% and 9.7% under RCP 4.5 and RCP 8.5, respectively. This indicates slightly wetter conditions in the future under RCP8.5 as compared to RCP4.5.

The GFDL-ESM2M model projects the lowest increase (1.2%) in rainfall in the 2010-2039 future period under RCP8.5, while the CanESM2, projected the highest (26.3%) increase in rainfall for the period 2070-2099 under RCP8.5 (Table 7).

Table 7. Mean change in projected climate between baseline (1976-2005) and the three future time slices (2010-2039, 2040-2069 and 2070-2099) periods for RCP 4.5 and RCP 8.5

Name of Model	Parameter	RCP 4.5			RCP8.5		
		2010-2039	2040-2069	2070-2099	2010-2039	2040-2069	2070-2099
GFDL-ESM2M	Maximum Temperature (°C)	0.7	1.3	1.7	0.9	2.0	3.2
	Minimum Temperature (°C)	1.1	1.7	2.1	1.2	2.4	3.8
	Mean Temperature (°C)	0.9	1.5	1.9	1.1	2.2	3.4
	Rainfall (%)	1.5	1.9	6.6	1.2	3.9	15.6
	Solar Radiation (%)	-0.6	-0.7	-0.9	-0.1	-0.9	-1.6
CanESM2	Maximum Temperature (°C)	1.0	1.8	2.4	1.0	1.1	2.4
	Minimum Temperature (°C)	1.2	2.2	2.7	1.5	3.0	4.8
	Mean Temperature (°C)	1.1	2.0	2.6	1.3	2.1	3.1
	Rainfall (%)	6.8	9.5	14.7	5.4	11.3	26.3
	Solar Radiation (%)	-1.2	-2.5	-1.1	-2.3	-1.6	-1.9
NorESMI-M	Maximum Temperature (°C)	0.6	1.2	1.3	0.6	1.7	2.9
	Minimum Temperature (°C)	1.0	1.6	1.9	1.1	2.2	3.6
	Mean Temperature (°C)	0.8	1.4	1.6	0.9	1.9	3.8
	Rainfall (%)	2.6	1.5	6.9	4.3	3.3	9.9
	Solar Radiation (%)	-1.4	-1.2	-2.3	-1.6	-1.9	-2.5
Ensemble	Maximum Temperature (°C)	0.8	1.4	1.8	0.8	1.8	3.2
	Minimum Temperature (°C)	1.0	1.8	2.2	1.2	2.4	4.0
	Mean Temperature (°C)	0.9	1.6	2.0	1.0	2.1	3.6
	Rainfall (%)	5.0	9.7	12.3	6.2	8.9	20.5
	Solar Radiation (%)	-0.8	-1.1	-1.3	-0.8	-1.1	-1.6

3.4 Impact of Climate Change on Phenological Parameters

Within the study area the early season cultivar took an average of 73 and 70 days to flower and the long season cultivar took an additional 11 and 8 days for the March to May and October to December (MAM and OND) growing season, respectively under present climate. With climate change, the days to 50% flowering decreased.

During the MAM season, the number of days for gadam (seredo) to attain 50% flowering was reduced by 11 (12), 16 (18) and 19 (22) days under RCP4.5 and by 11 (11), 19 (22) and 26 (32) days under RCP8.5 for the near term, mid century and end century, respectively. During the OND season, the number of days for the gadam (seredo) to reach 50% flowering reduced by 6 (9), 11 (12) and 13 (15) days for the near term, mid century and end century, respectively, under RCP4.5 and 7

(8), 14 (15) and 21 (23) days, respectively under RCP8.5 (Table 8). This outcome is attributed to increase in temperature and rainfall creating favorable conditions for sorghum growth and development. Increased temperature accelerates growth and development of sorghum and thus reducing the length from sowing to 50% flowering. Increased temperature leads to quick accumulation of heat units from sowing to 50% flowering; hence the sorghum plant flowered earlier [74].

The decline was relatively higher during the MAM season as compared to the OND season, implying that the number of days to 50% flowering will be less during the MAM growing season for the two varieties. The results also indicated that towards the end century (2080's) under both RCPs there will be great decline in the days to 50% flowering when compared to the current climate (baseline).

The decrease in days to 50% flowering, under climate change revealed in this study is corroborate findings obtained by [75], who reported that flowering dates for the short (long) duration sorghum cultivars reduced by 12 (13) and 29 (32) days with +1°C and +3°C increase in temperature, respectively in Katumani, Kenya.

Table 8. Percentage mean changes on days to 50% flowering at 0 and 50N fertilizer application rates between baseline and three future periods for the CORDEX models and two Representative Concentration Pathways (RCPs): 4.5 and 8.5 for the two cultivars two cultivars during the MAM and OND growing seasons

N-levels (kg ha ⁻¹)	CORDEX Models	GADAM						SEREDO					
		2010-2039		2040-2069		2070-2099		2010-2039		2040-2069		2070-2099	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
0N (MAM)	CanESM2	-14.7	-13.4	-24.7	-25.4	-29.1	-35.5	-14.8	-12.5	-26.9	-27.2	-31.4	-38.8
	NorESMI-M	-12.4	-13.5	-19.0	-23.7	-21.0	-33.1	-16.2	-14.4	-15.9	-25.6	-22.5	-36.1
	GFDL-ESM2M	-13.4	-15.2	-18.3	-25.7	-23.6	-34.6	-17.5	-16.2	-19.4	-28.1	-25.6	-37.9
	Ensemble	-13.9	-15.3	-21.2	-25.7	-24.9	-35.2	-14.9	-15.2	-22.3	-27.9	-26.9	-38.6
50N (MAM)	CanESM2	-15.2	-14.0	-25.2	-25.9	-29.5	-35.9	-15.5	-11.7	-26.3	-26.6	-30.8	-38.2
	NorESMI-M	-13.1	-14.1	-19.5	-24.2	-21.5	-33.6	-15.3	-11.8	-19.4	-24.9	-21.7	-35.5
	GFDL-ESM2M	-13.9	-15.7	-18.8	-26.2	-24.1	-35.0	-16.5	-18.4	-17.8	-27.5	-24.9	-37.4
	Ensemble	-14.4	-15.8	-21.7	-26.2	-25.4	-35.6	-17.0	-14.4	-21.5	-27.2	-26.6	-38.0
0N (OND)	CanESM2	-10.2	-8.2	-18.5	-19.3	-22.6	-29.4	-13.4	-9.2	-18.6	-19.5	-23.0	-30.0
	NorESMI-M	-7.8	-8.6	-13.1	-17.3	-15.1	-26.8	-9.8	-9.2	-15.2	-18.0	-16.4	-27.5
	GFDL-ESM2M	-8.5	-10.0	-14.1	-19.4	-17.4	-28.4	-10.4	-10.9	-14.8	-19.9	-18.8	-29.2
	Ensemble	-8.9	-10.0	-15.5	-19.2	-18.7	-29.1	-11.3	-11.4	-16.4	-19.3	-18.8	-29.7
50N (OND)	CanESM2	-9.8	-7.8	-18.1	-18.9	-22.2	-29.1	-13.4	-10.1	-19.6	-19.5	-23.1	-30.0
	NorESMI-M	-7.3	-8.2	-12.7	-16.9	-14.7	-26.4	-9.5	-10.1	-15.2	-18.0	-16.4	-27.5
	GFDL-ESM2M	-7.6	-9.5	-13.7	-19.0	-17.0	-28.0	-10.1	-11.7	-14.7	-20.0	-18.8	-29.2
	Ensemble	-8.4	-9.5	-15.1	-18.8	-18.3	-28.7	-11.2	-11.7	-15.0	-19.3	-18.8	-29.7

The time to physiological maturity was also shortened by the increased temperatures and wetter future. The mean number of days taken by the gadam (seredo) cultivars to reach physiological maturity was 137 (143) and 123 (126) during MAM and OND growing season,

respectively. With climate change comparable trends were observed for decline in days to maturity as in days to 50% flowering.

During the MAM season, the number of days for gadam (seredo) to attain maturity was reduced by 14 (17), 23 (25) and 27 (30) days under RCP4.5 and by 15 (17), 28 (31) and 42 (45) days under RCP8.5 for the near term, mid century and end century, respectively. During the OND season, the number of days for the gadam (seredo) to attain maturity reduced by 9 (11), 15 (16) and 19 (20) days for the near term, mid century and end century, respectively, under RCP4.5 and 10 (11), 20 (21) and 29 (31) days, respectively under RCP8.5 (Table 9). The delayed and earlier days to maturity under the baseline climate and changed climate is attributed to slower and quick accumulation of heat units during the growth phase, respectively. It is also evident that both cultivars matured much earlier during the short rains than during the long rains.

All GCMs indicate that under both RCPs, the approach to the end century (2080's) showed a greater decline in the days to maturity when assessed against the current climate (baseline). These trends are also consistent with [53] in which the end century (2071-2100) showed the greatest shortening in the crop cycle duration.

The reduction in days to maturity revealed in this study is in conformity with other results obtained by other researchers [33, 6, 76, 77, 53]. For example, [33], noted that the growing season for sorghum was becoming shorter, the days shrunk by 8 and 4 days in the sand veldt and the hard veldt regions, respectively, in Botswana.

Table 9. Percentage mean changes on days to physiological maturity at 0N and 50N fertilizer application rates between baseline and three future periods for the CORDEX models and two Representative Concentration Pathways (RCPs): 4.5 and 8.5 for the two cultivars during the MAM and OND growing seasons

N-levels (kg ha ⁻¹)	CORDEX Models	GADAM						SEREDO					
		2010-2039		2040-2069		2070-2099		2010-2039		2040-2069		2070-2099	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
0N (MAM)	CanESM2	-13.2	-10.7	-20.9	-21.3	-24.8	-31.2	-14.4	-11.7	-21.3	-22.2	-25.8	-32.5
	NorESMI-M	-10.2	-10.9	-15.9	-20.4	-17.6	-29.1	-11.5	-11.7	-16.0	-20.4	-17.6	-30.0
	GFDL-ESM2M	-11.1	-12.6	-16.5	-22.2	-19.7	-30.5	-12.3	-13.4	-17.1	-22.5	-20.2	-31.7
	Ensemble	-11.3	-12.4	-17.5	-21.6	-21.0	-31.1	-12.0	-12.7	-17.6	-22.1	-21.3	-32.3
50N (MAM)	CanESM2	-11.0	-8.4	-18.8	-19.3	-22.9	-29.5	-12.1	-9.4	-19.5	-20.4	-24.0	-30.9
	NorESMI-M	-8.0	-8.6	-13.7	-18.3	-15.6	-27.3	-9.3	-9.7	-15.6	-18.5	-15.7	-28.4
	GFDL-ESM2M	-8.8	-10.4	-14.5	-20.2	-17.9	-28.7	-10.3	-12.0	-16.1	-20.8	-18.4	-30.2
	Ensemble	-9.1	-10.1	-15.6	-19.5	-18.9	-29.3	-10.4	-14.3	-16.2	-20.3	-19.6	-30.7
0N (OND)	CanESM2	-8.9	-7.4	-15.1	-15.7	-18.5	-23.9	-10.0	-6.9	-14.9	-15.3	-18.4	-24.0
	NorESMI-M	-6.6	-7.5	-10.8	-14.6	-12.2	-22.0	-7.2	-7.3	-11.6	-14.8	-13.0	-22.0
	GFDL-ESM2M	-7.3	-9.0	-11.2	-16.2	-14.2	-23.3	-7.8	-8.8	-11.9	-15.9	-14.8	-23.2
	Ensemble	-7.7	-8.5	-12.4	-15.8	-15.2	-23.7	-8.3	-8.6	-13.1	-15.6	-15.2	-23.8
50N (OND)	CanESM2	-8.6	-7.3	-14.9	-15.6	-18.4	-23.8	-11.1	-8.4	-16.7	-16.4	-19.4	-25.0
	NorESMI-M	-6.4	-7.4	-10.9	-14.7	-12.1	-21.9	-8.2	-8.7	-11.8	-15.6	-14.1	-22.7
	GFDL-ESM2M	-7.3	-8.8	-11.5	-16.1	-14.2	-23.2	-9.0	-9.8	-13.0	-17.0	55.3	-24.3
	Ensemble	-7.5	-8.4	-12.2	-15.5	-15.1	-23.6	-9.4	-10.0	-13.8	-16.8	-16.2	-24.7

3.5 Impact of Climate Change on Sorghum Biomass

Under both current and changed climate, the long season variety, seredo, gives higher above ground biomass than the short season variety gadam, with slight increase or decrease in biomass for both varieties under climate change (Table 10). Biomass yields of Gadam for the MAM and OND growing season are reduced by 0.5-2.6% and 3-6.3%, respectively under both RCPs with no nutrient application. With application of 50N, there was a slight increase of biomass. For seredo, biomass yields increased insignificantly under both RCPs except during the OND growing season with no fertilizer application, which depicted a reduction in the biomass. The small % changes in biomass reflect little or no effect of changes in rainfall and temperature as represented by RCP4.5 and RCP8.5.

The decline of biomass production is as a result of reduction of crop cycle duration that was brought about by increased temperatures which affected the growth cycle through quicker accumulation of heat units consequently reducing the phenophase duration, thus reduction in biomass yield [84]. The general decline in biomass, due to impacts related to climate change on sorghum has also been revealed in other studies [48, 50, 53]. For example, [50] noted that under combined effects of reduced rainfall and increased temperature the total biomass of sorghum will reduce by 27% in the 21st century.

3.6 Impact of climate change on sorghum grain yield

APSIM-sorghum model indicates that all GCMs predict a brighter future for sorghum growth because continuous increases in sorghum yield are projected from the baseline period to 2080 period under both RCPs. The average mean yields for gadam under both current and changed climate during the two growing seasons was higher than for seredo.

During the MAM growing season, sorghum yields were projected to increase. The increase varied between 9.3% and 19.2% in the near term, 12.2% and 34.1% in the mid-century and 15.9% and 50.6% at the end of the century with no fertilizer application (Table 11). However, with 50N application the grain yield slightly increased varying between 11.1% and 21.8%, between 15.3% and 37.5% and between 19.8% and 58.2% in the near term, mid-century and towards end of the century, respectively.

During the OND growing season, sorghum yields were also projected to increase. The increase varied between 5.8% and 10.9% in the near term, 6.0% and 15.9% in the mid-century and 7.1% and 20.6% at the end of the century with no fertilizer application (Table 11). However, with 50N application the grain yield slightly increased varying between 8.8% and 13.3%, between 11.5% and 21.4% and between 13.6% and 30.6% in the near term, mid-century and end of the century, respectively.

The magnitude of change in the yield was higher for seredo than for gadam. Highest values were also noted in MAM especially towards the end century (2070-2099), with values of up to 85.3% (Table 11). Increased sorghum yields revealed by nearly all GCMs under the two RCPs, is attributed to increased projected temperatures and rainfall which tend to create conducive environment for the growth of sorghum. The study results are consistent with the observations by [78, 33, 79-81, 75, 43], which showed increase in sorghum grain yields under changed climate in specific regions. However, the results are dissimilar with those of [40, 49, 3, 50, 82, 83, 52]. For example [3] indicated that potential yield in the ASALs will decrease with climate change.

Table 10. Percentage mean changes on biomass at 0N and 50N fertilizer application rates between baseline and three future periods for the CORDEX models and two Representative Concentration Pathways (RCPs): 4.5 and 8.5 for the two cultivars during the MAM and OND growing seasons

N-levels (kg ha ⁻¹)	CORDEX Models	GADAM						SEREDO					
		2010-2039		2040-2069		2070-2099		2010-2039		2040-2069		2070-2099	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
0N (MAM)	CanESM2	-0.2	6.6	-2.6	5.1	-3.3	-1.7	1.1	10.0	-0.3	10.5	-0.6	8.1
	NorESMI-M	0.3	1.4	-2.6	-4.2	-0.6	-8.5	1.7	3.0	-1.1	-2.0	1.7	-4.0
	GFDL-ESM2M	-0.4	-1.5	-2.8	-5.4	-2.8	-8.4	1.0	-0.4	-1.2	-3.2	-0.8	-3.3
	Ensemble	0.1	1.3	-0.1	-1.9	-0.9	-7.0	1.2	2.7	1.8	0.6	1.4	-1.0
50N (MAM)	CanESM2	1.0	8.6	-0.4	9.4	-0.8	5.4	1.9	11.7	1.6	14.5	1.9	15.4
	NorESMI-M	1.3	2.5	-1.2	-2.3	1.4	-5.4	2.4	3.9	-0.1	-0.4	3.3	-0.9
	GFDL-ESM2M	0.6	-0.5	-1.4	-3.5	-0.8	-4.8	1.6	0.2	-0.2	-1.5	0.8	0.2
	Ensemble	1.0	2.5	1.8	0.5	1.4	-2.5	1.8	3.6	3.3	2.7	3.4	3.1
0N (OND)	CanESM2	-1.5	1.6	-5.7	-2.4	-7.8	-9.4	0.8	4.4	-2.7	1.7	-4.0	-2.2
	NorESMI-M	-1.4	-0.8	-4.9	-7.3	-3.7	-13.0	0.5	1.4	-2.3	-4.4	-0.8	-8.5
	GFDL-ESM2M	-2.0	-2.9	-5.1	-8.3	-5.4	-13.1	0.0	-0.8	-2.4	-5.5	-2.6	-8.3
	Ensemble	-1.1	-0.6	-2.7	-5.4	-4.4	-12.7	1.0	1.8	0.3	-2.4	-1.4	-7.4
50N (OND)	CanESM2	1.9	6.0	-0.8	4.4	-2.3	0.5	3.2	7.8	2.3	8.8	2.0	7.4
	NorESMI-M	1.4	2.4	-1.2	-2.8	0.7	-7.1	2.3	3.6	0.4	-0.1	3.4	-1.9
	GFDL-ESM2M	0.8	0.0	-1.2	-3.6	-0.8	-7.1	1.9	0.9	0.6	-0.7	1.8	-1.2
	Ensemble	1.8	2.7	1.7	-0.2	0.6	-5.9	2.8	4.1	4.4	3.0	3.7	0.2

Table 11. Percentage mean changes on grain yield at 0N and 50N fertilizer application rates between baseline and three future periods for the CORDEX models and two Representative Concentration Pathways (RCPs): 4.5 and 8.5 for the two cultivars during the MAM and OND growing season

N-levels (kg/ha-1)	CORDEX Models	GADAM						SEREDO					
		2010-2039		2040-2069		2070-2099		2010-2039		2040-2069		2070-2099	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
0N (MAM)	CanESM2	10.2	22.6	15.2	30.3	17.7	30.7	17.4	32.0	30.2	53.1	35.9	72.4
	NorESMI-M	9.1	12.5	9.3	11.5	15.4	13.8	16.5	15.6	16.8	24.9	27.7	37.8
	GFDL-ESM2M	8.2	7.3	9.0	10.0	12.9	15.1	15.8	10.7	18.3	25.5	26.3	42.9
	Ensemble	9.6	12.7	15.4	16.8	17.5	19.1	14.5	18.4	27.0	32.9	33.0	49.4
50N (MAM)	CanESM2	12.3	25.5	19.0	37.4	22.4	45.0	17.9	33.6	32.6	59.0	39.3	85.3
	NorESMI-M	11.1	14.1	12.0	14.9	18.8	20.1	16.5	17.1	18.8	27.0	29.7	42.8
	GFDL-ESM2M	9.9	9.0	11.4	13.6	16.4	22.8	15.9	14.9	19.2	28.0	28.5	48.6
	Ensemble	10.9	14.3	18.7	21.1	21.5	28.3	16.6	19.2	28.8	35.8	35.9	56.2
0N (OND)	CanESM2	6.7	10.6	6.9	12.5	6.1	9.7	12.0	13.9	15.4	23.0	16.8	29.8
	NorESMI-M	5.3	7.0	4.0	4.0	7.5	1.9	8.2	10.0	10.7	12.1	14.8	15.5
	GFDL-ESM2M	4.8	4.1	4.4	3.4	6.2	2.3	8.3	8.4	10.9	12.1	14.6	17.5
	Ensemble	6.2	7.7	8.7	7.5	8.4	3.6	9.7	11.6	16.0	16.3	16.8	19.4
50N (OND)	CanESM2	10.7	14.7	13.6	21.3	14.6	27.0	14.1	17.5	21.0	30.4	24.0	42.6
	NorESMI-M	7.8	9.8	8.2	9.6	12.7	11.8	9.6	11.9	12.8	16.0	19.0	23.5
	GFDL-ESM2M	7.7	7.2	10.2	9.6	11.6	13.1	9.8	9.6	13.4	16.9	18.9	26.7
	Ensemble	9.1	11.1	13.8	14.3	15.3	16.0	11.2	14.0	19.4	22.1	22.1	29.6

Conclusion

The APSIM-Sorghum model (version 7.8) was effectively calibrated and evaluated for semi-arid eastern Kenya. Calibrated and validated APSIM sorghum model can be employed to simulate climate change impacts on sorghum growth and development in semi-arid eastern Kenya, using climate projections data of three CORDEX GCMs and the ensemble and considering RCP 4.5 and RCP 8.5.

The results demonstrated reduction on phenological dates of sorghum, with more reduction being witnessed during MAM growing season under RCP8.5 and in the end century (2071-2100). Under both current and changed climate, the long season variety, seredo, gives higher above ground biomass than the short season variety gadam. There was slight increase or decrease in biomass for both varieties under climate change. Also noted is that under changing climate sorghum grain yields will constantly increase for both cultivars over the three time slices with up to 85.3% increase in the end of the century (2070-2099). The magnitude of change in the yield was higher for seredo than for gadam.

Conflict of Interest

The authors declare that they have no conflict of interests

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