Predicting Maize (Zea mays) Productivity under Projected Climate Change with Management Options in Amhara Region, Ethiopia

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Abstract

Maize is an important cereal crop in Ethiopia. Yield of maize has been declined in Ethiopia mainly due to water scarcity, low soil fertility and heat stress. Currently, limited technologies are available in the study region that increases maize productivity. If crop models are properly calibrated, they are effective tools to study crops responses to environmental factors. Assessing impact of future climate on maize crop may help to develop adaptation strategies. The objectives of this study were (1) to calibrate and evaluate the CERES maize model in DSSAT technology for simulating phenology and yield of maize (2) to assess impact of projected climate change on maize productivity (3) to develop promising management practices for maize. The impact of projected climate change was assessed using the 17 GCMs (CMIP5) run under RCP4.5 and RCP8.5 climate scenarios. Two water regimes treatments (rainfed and irrigated) and four rates of nitrogen (0, 46, 92 and 138 kg ha^{-1}) were evaluated individually and in combinations for their effectiveness to increase maize productivity under the projected climate conditions. The model evaluation result revealed that the RMSE values were 2.5 days for anthesis, 4.4 days for physiological maturity, 258.3 kg ha^{-1} for grain yield and 1034 kg ha^{-1} for above ground biomass yield with nRMSE values of 3%, 4%, 4.7% and 10%, respectively. The d-index values were 0.87, 0.80, 0.88 and 0.71 for the respective parameters. The good agreement between the simulated and the measured values indicated the maize genetic coefficients in the model were properly calibrated. The simulation results at Tehuledere site showed that maize grain yield may decrease by 11% and 20% in 2030s and by 26% and 29% in 2050s under RCP4.5 and RCP8.5 scenarios, respectively whereas in Kallu site yield may decrease by 13% and 15% in 2030s and by 17% and 19% in 2050s for the respective RCP scenarios. However, the management scenarios have shown that maize yield may substantially increase by the use of optimum nitrogen fertilizer and supplemental irrigation. Thus, it can be generalized that climate change may adversely affect maize production in the Semi-arid regions of Ethiopia but the impact could be reversed by using sound crop management practices.

1. Introduction

Food shortage is the main challenge of the semi-arid and arid regions of Ethiopia. Climate change is suggested the major deriver behind the problem (CSA, 2011). A study conducted by Kurukulasuriya *et al,* (2006) showed that high temperature and rainfall variability significantly influenced the agriculture sector in Ethiopia. At present, the food production system in Ethiopia is affected by climate changes because climate can directly influence the productivity of major crops (Wheeler and von Braun, 2013). Developing countries are more affected by climate change as the crop production system in these countries is directly depending on rainfall (IPCC, 2012). The study by Kurukulasuriya *et al.* (2006) and Muller *et al.* (2011) showed that climate change affected the economy of most countries in Africa. Studies also showed that climate change significantly influenced crops production in different countries (Muluneh *et al.* 2015). Hadgu *et al,* (2015) and Kassie *et al.* (2013) also reported that the livelihoods of people in Ethiopia were significantly affected by climate change. The majorities of people in Ethiopia are directly depending on rainfed production systems and are liable to impact of climate change. Change in rainfall amount and patterns in the future may negatively affect the small scale farming system in Ethiopia. According to Hadgu *et al.,* (2015) extra warming projected in 2030s and 2050s may significantly affect the Ethiopian agricultural system. Thus, developing countries may be at the highest risk due to their low adaptive capacity to the changing climate. Crop failure is a frequent phenomenon in the rainfed system of semi-arid and arid areas of Ethiopia (Kassie *et al.,* 2013). Cereal crops such as sorghum, teff and millet are dominant. The early offset of rainfall in the study area limits crop productivity. Water deficit occurs during the flowering and the grain filling stages of the crops that leads to significant yield reduction. As maize is highly sensitive to water deficit and heat stress yield is more affected as compared to the other cereal crops.

Maize (*Zea mays* L.) the major food crop well adapted in Ethiopia and in many Africa countries. Among the 22 maize-growing countries globally, sixteen are in Africa (Nuss and Tanumihardjo, 2011). Maize is called the queen of cereal crops because of the high yield potential. In Ethiopia, maize is majorly produced by small-scale farmers. CSA (2017). Maize ranks the second after teff (*Eragrostis teff*) in area coverage and the first in total production. The low cost of production and its high yield potential make maize the most popular crop in many countries (Nurudeen, 2011). In addition, maize is well adapted to a wide range of agroecologies (Paterson *et al.,* 2009). The average national yield of maize in Ethiopia is 3900 kg ha^{-1} which is far below the world's average (5660 kg ha^{-1}). Studies showed that maize productivity has been declined from time to time (CSA), 2017) due to several factors such as frequent droughts, decline in soil fertility, poor agronomic practices, limited use of inputs, insufficient technologies, lack of credit, low seed quality, diseases, pests and weeds (Taffesse *et al.,* 2011; Erkossa *et al.* 2007).

In Ethiopia, there are limited technologies that can improve maize productivity particularly in the arid and semi-arid areas (Bryan *et al.* (2009). Studies showed that adaptation strategies such as the use of improved maize cultivars and changing the current maize sowing date have been found successful to improve maize productivity (Nouria *et al.,* 2017). Optimum fertilizer application was also effective to reduce effect of water and temperature stresses (Smith *et al.,* 2020). He *et al.* (2018) studied the response of maize to fertilizer under future climate using the DSSAT technology and showed that soil physical quality, nutrient availability, and soil microbial diversity were significantly improved (Reynolds *et al.,* 2014). Ma *et al,* (2018) also reported that the use of legume crops in rotation system reduced the adverse effects of climate change on crops in rainfed agriculture system. However, research findings regarding adaptation strategies for maize crop in Ethiopia is highly scarce.

Crop models have been used to predict crop phenology, growth, and yield in response to environmental factors. If models are properly calibrated, they are effective tools to study crops responses to environmental factors (Ruane *et al.,* 2013). Crop models can identify options by increasing our understanding the impacts of climate change on crops. A study by Bhupinde (2018) showed that DSSAT technology has been used for different applications such as for soil fertility management, evaluating crop response to irrigation, analyzing yield gap, studying genotype by environment interaction, assessing effect of future climate on crops, for risk management, and identifying adaptation strategies. Li *et al,* (2015) used the DSSAT package to predict crop biomass, yield, soil nitrogen, and water balance under different environments and managements. However, crop models need to be calibrated in new environment and cropping practices. There are very limited experiences in using crop models to solve crop production problems in Ethiopia, Most studies emphasized on large-scale areas (Kassie *et al.,* 2015) while some focused on economic aspects (Mideksa, 2010). Overall, there are very limited adaptation strategies in the arid and semi-arid areas of Ethiopia that address the impact of climate change on maize production (Alemayehu and Bewket, 2016). Therefore, assessing impact of projected climate change on maize production at local scale has significant implications for designing suitable adaptation strategies. Thus, this study was conducted (1) to calibrate and evaluate the CERES-maize model in DSSAT technology for simulating phenology and yield of maize (2) to assess how future climate will likely affect maize production in the study areas and (3) to identify potential adaptation strategies that can sustain maize production in the study region.

2. Materials And Methods

2.1. Description of the Study Areas

The study was conducted in *Tehuledere and Kallu Woredas* (*local administrations*) located in the Amhara National Regional State, Ethiopia. *Tehuledere Wereda* is situated at 39° 38’ 00” E and 11° 45’ 00” N with an elevation of 1680 meter above sea level (masl) and characterized as mid altitude. The long-term average total rainfall is 1200 mm with average annual temperature of 22°C. The soil texture is clay loam. *Kallu Wereda* is located at an elevation of 1465m which is characterized as low altitude with geographic coordinates of 10° 43’ 12”.N and 39° 49’ 48” E. It receives an average annual rainfall of 1098mm with mean maximum and means minimum temperatures of 27.7°C and 12.5°C, respectively. The major crops commonly grown in the study areas are sorghum (*Sorghum bicolor* L.), teff (*Eragrostis teff*), maize *(Zea mays*), chickpea (*Cicer arietinum*), and mung bean (*Vigna radiate*). Both areas are located under the semi-arid tropical belt and characterized by mixed farming (crop-livestock production systems). The rainfall pattern at both areas is bimodal with short rainy season (locally known as *Belg*) that extends from February to April while the long rainy season (locally known as *Kiremt*) extends from June to September. The convergence in low-pressure systems associated with the Inter-Tropical Convergence Zone (ITCZ) is the major cause for the main rain season whereas the humid easterly and south easterly winds from the Indian ocean are the causes for the short rain season (NMA, 2007; Seleshi and Zanke, 2004). Most field crops are rainfed but horticultural crops such as onion, tomato, carrot, garlic, papaya and mango are produced by using irrigation.

2.2. Description of the DSSAT package and the CERES-maize model

The present study used the DSSAT (V4.7.5) package for assessing climate change impact on maize production and to identify suitable crop management scenarios. The DSSAT has been used for predicting growth, development, and yield of several crops (Jones *et al.*, 2003). It has been used by researchers, educators, consultants, extension agents, crop growers and policy makers across the world (Jones *et al.*, 2003). At present, the DSSAT package consists of more than 42 crop models for cereals, legumes, fruits, fibers, oil, sugar, vegetables, and forage crops. It is process-oriented and can work independently of location, season, cultivar, and management practices. The DSSAT technology can predict phenology, growth and yield as a function of soil, weather, crop and agronomic practices (Andrew et al., 2007). Climate change impact analysis, selection of technologies (management practices), and identification of suitable adaptations strategies are possible using the DSSAT technology (He et al., 2018). It is capable to optimize yield of several crops (He *et al.*, 2016). He et al., (2018) used the DSSAT technology to study climate change impact on crops and to explore effective adaptation strategies. However, the DSSAT technology requires inputs of weather, soil characteristics, crop characteristics, and crop managements (Hoogenboom et al., 2012).

The Crop-Environment-Resource-Synthesis (CERES)-maize model is one of the crop models in the DSSAT and has components of vegetative and reproductive development, carbon balance, water balance, and nitrogen balance (Singh and Virmani, 1996). The model can simulate growth, development, and yield on a daily time step from sowing to the maturity of the crop. Differences in growth, development, and yield are influenced by genetic coefficients (cultivar-specific parameters). Maize physiological processes in response to weather, soil and management practices can be well simulated by using the model. The model can also simulate soil-water, nitrate transport, carbon balance, and nitrogen turnover (Gabrielle and Kengni, 1996). Crop germination date, emergence date, juvenile stage, floral induction, 75% silking date, beginning of grain filling, maturity, and crop harvest date can be simulated by the model (Gabrielle and Kengni, 1996). The detailed description of the CERES-maize model is found in Jones *et al.*(2003).

2.3. Model Inputs

2.3.1. Collected experimental data for calibrating and evaluating the model

For the determination of genetic coefficients of the maize cultivar (*BH-540)*, phenological and yield data were collected from field experiments conducted in Tehuledere *Wereda* during the 2018 main cropping season. The treatments were four levels of nitrogen (0, 46, 92 and 138 kg ha^{-1}) and two levels of water regimes (rainfed and irrigated) set out in a Randomized Complete Block Design (RCBD) in factorial arrangement with three replications. *The irrigated treatment received three* supplemental irrigation of 100mm water applied in 10 days interval starting the anthesis stage of the maize crop with the aim to minimize effect of terminal water deficit. The crop was sown with spacing of 0.75 m * 0.25 m inter and intra row spacing, respectively. The recently recommended blended fertilizer (NPSB) with nutrient contents of 18.9% N, 37.7% P_2O_5, 6.95% S and 0.18% B was used for all the treatment at a rate of 100 kg ha^{-1} while nitrogen nutrient in form of Urea (46%N) was applied based on the treatments. All the NPSB fertilizer was applied during the sowing time of the maize crop whereas the urea was applied in split (half during sowing time and the remaining half top dressed at the knee-height stage of the maize crop).

Data on anthesis, physiological maturity, leaf area index, grain yield at harvest, and aboveground biomass yield at harvest were collected from the best-performing treatment (92 kg N ha^{-1} under supplemental irrigation) for calibrating the cultivar genetic coefficients. Phenological data (anthesis date, sinking date, and physiological maturity date) were recorded on a plot base. Days to anthesis were recorded as the number of days from the date of sowing to the time when 50% of the plants in a plot showed the first flower whereas days to physiological maturity was determined by sampling two cobs per plot in two days intervals by assessing the presence of black layers at the base of the grains. Aboveground dry biomass and grain yield were determined by sampling two maize rows in each plot during harvest and were measured after drying at 80°C for 48 h in an oven. In addition, aboveground biomass yield and leaf area index were measured from five plants randomly selected from each plot and were recorded in 10 days interval throughout the growing period of the maize crop. The dry weights of the sample plants were determined after oven-drying to a constant weight. Leaf area was measured at 50% silking by multiplying leaf length with maximum leaf width and adjusted by correction factor of 0.75 (0.75 * leaf length * maximum leaf width) as suggested by Francis et al., (1969). Thus, the Leaf area index (LAI) was calculated by dividing the leaf area by the sampled ground area. For the evaluating the crop model, phenological and yield data of the cultivar were obtained from yield trials conducted during 2013, 2014, 2015, 2016, and 2017 in the study region.

2.3.2. Maize management data

The CERES-maize model requires crop management information for the cultivar for simulating growth, development and yield. The cultivar with specific genetic coefficients, initial soil conditions, sowing date, sowing depth, plant spacing, simulation start date, soil type, fertilizer management, fertilizer types, time of fertilizers application and depth of application were inputs for the crop model for simulating phenology, growth and yield. These data were obtained from variety adaptation trials conducted in the study region

2.3.3. Soil parameters

Soil profiles that are representative of the study areas were opened at a depth of 160 cm at both sites. The soil samples were collected based on horizon in the profiles and were analyzed for determination of soil texture, pH, cation exchange capacity (CEC), electrical conductivity (EC), organic carbon, total nitrogen, and available phosphorus. In addition, soil bulk density, field capacity, permanent wilting point, water saturation, and saturated hydraulic conductivity were estimated from the soil texture by using the SBuild program in the DSSAT package. The soil texture was determined by the modified Bouyoucos hydrometer method (Bouyoucos, 1962) using sodium hexametaphosphate as dispersing agent. The soil pH was determined potentiometrically using a digital pH meter in a 1:2.5 soil water suspension (Van Reeuwijk, 2002). Organic carbon was determined by wet digestion method whereas total nitrogen was determined through Kjeldahl digestion, distillation and titration procedures of the wet digestion method (Black, 1965). Available phosphorus was determined colorimetrically using Olsen's method (Olsen, 1954). The Cation exchange capacity was estimated titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution (Chapman, 1965). The soil parameters were analyzed at Sirinka Agricultural Research.

2.3.4. Climate data and RCP scenarios

Daily weather data of maximum and minimum temperatures (°C), daily precipitation (mm), and daily total solar radiation (M J $M^{-2}day^{-1}$\`) were used as inputs for the model. These data were obtained from the nearest weather stations at *Haik* and *Kombolcha* located 5 km and 10 km distance from the experimental field, respectively whereas historical (baseline) daily data for the period 1981 to 2010 were obtained from the National Meteorological Agency in Addis Ababa, Ethiopia. Data gaps were filled using a monthly bias-corrected version of the closest grid point of the AgMERRA data set following standard procedure (AgMIP, 2013a, and b). Future daily weather data for 2030s (2020–2049) and 2050s (2040–2069) were obtained from the output of 17 CMIP5 global circulation models (GCM) run under RCP 4.5 and RCP 8.5 climate scenarios and downloaded from the International Center for Tropical Agriculture (CIAT) portal (http://ccafs-climate.org/). The models outputs were downscaled to the target areas using the MarkSim software package (Jones and Thornton, 2013). Two climate change scenarios (RCP4.5 and RCP8.5) were used to predict impact of projected climate change on maize production and to identify suitable adaptation strategies. The study assumed effect of CO_2 fertilization and 380 ppm of CO_2 was used for the baseline climate whereas 423 ppm and 432 ppm were used for the 2030s whereas 499 and 571 ppm were used for the 2050s under the RCP 4.5 and RCP8.5 scenarios, respectively. RCP's are greenhouse gas concentration trajectories adopted by the IPCC for its fifth assessment (IPCC, 2013). In the RCP4.5 scenario, Greenhouse gas (GHG) 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 whereas, in RCP8.5, greenhouse gas emission (GHG) 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.

2.3.5. Model calibration and evaluation procedures

The CERES-maize model consists of six crop genetic coefficients. Thus, to estimate the coefficients maize data on anthesis date, physiological maturity date and yield were collected from field experiment conducted in Tehuledere Wereda during the 2018 main cropping season. The model calibration was performed first by adjusting small change (+ 5%) for each parameter and also using trial and error method until the predicted and the measured data were very close to each other. In the process, the coefficients that determine phenology of maize were first adjusted followed by those coefficients that affect the growth, yield, and yield components. The performance of calibrated model was evaluated using independent set of data of phenology (anthesis and physiological maturity), growth, and yield data of 2013, 2014, 2015, 2016, and 2017 obtained from in the study region. The results of both model calibration and evaluation were statistically evaluated using coefficient of determination (R^2), the index of agreement (d) (Willmott *et al.*, 1985), and the mean square error (RMSE) (Loague and Green, 1991) by comparing the observed and the simulated values.

Where n = number of observations, Pi = predicted value for the ith measurement and Oi = observed value for the ith measurement. Thus, lower value indicates good fit of the model.

$$\text{n}RMSE = \frac{RMSE}{N} x100$$

Where N is the mean of the observed variables. nRMSE gives the measure (%) of the relative difference between simulated and observed data. Less value indicates good fit of the model

$$d = 1 - \left[\frac{\sum_{i=1}^{n} (Pi - Oi)^2}{\sum_{i=0}^{n} (|Pi - O|) + (|Oi - O|)^2} \right]$$

The d-statistic was calculated as (0 ≤ d ≤ 1). The more values close to unity are regarded as best agreement between the predicted and observed data (Musongaleli et al., 2014). When d = 1 indicates excellent. Where n: number of observations, Oi and Pi are the observed and predicted values, respectively for the i^{th} data pair; and O is the mean of the observed values.

2.6. Analysis of projected climate change impact on maize production

In the simulation, the baseline temperature and rainfall, also CO_2 concentration in the model were modified by the projected climate in 2030s (2020–2049) and 2050s (2040–2069) under RCP4.5 and RCP8.5 climate scenarios. The phenological and yield response of the cultivar *BH-540* to the baseline climate (1981–2010) and for the projected climate changes by 2030s and 2050s under both RCPs were assessed. Thus, change in phenology and yield under the baseline and future climates were compared as follows:

$$\text{changeinphenology}(\backslash\%) = \frac{XPredicted - Xbase}{Xbase} * 100$$

Where, X represents the anthesis or physiological maturity

$$\text{changeinGrainyield}(\backslash\%) = \frac{YPredicted - Ybase}{Ybase} * 100$$

Where, Y represents grain yield

2.7. Analysis of crop management scenarios for maize

Identification of promising crop management strategies are very important for the sustainable production of maize in the present and future climate conditions. Thus, this study evaluated effect of nitrogen fertilizer and supplemental irrigation as options to increase maize productivity under the projected climate change. We evaluated the impact of two water regimes (1) rainfed (*RF*) and (2) Supplemental irrigation (SI) and four rates of nitrogen (0, 46, 92, and 1380 kg N ha^{-1} individually and in combination for their effectiveness to increase maize yield under the present and future climate conditions. The water requirement of the maize crop and irrigation scheduling were estimated with the CRPWAT V.8 model. The water deficit at the flowering and grain filling stages of the maize crop was supplied as supplemental irrigation. The irrigated treatment received three irrigation of 100 mm water supplied in ten days interval starting the flower initiation stages of the maize crop. The irrigation water was supplied when the available soil moisture in the rooting depth reached 50% of its field capacity. The nitrogen was used in the form of Urea (46%N) all dose applied during sowing time.

For selecting promising management strategies for maize crop, the simulation was performed only for the grain and above ground biomass yields. The simulation results were statistically analyzed using the analysis of variance (ANOVA) techniques by using statistical analysis system (SAS, 2009). Treatments mean were compared using least significant test (LSD) at 5% probability level. In the analysis, years were considered as replications because the yield in one year under a given treatment was not affected by another year. Since, simulation years were unpredictable, formal randomization of simulation years was not needed. When we used ANOVA, we made the following assumptions: (1) individual observations are mutually independent; (2) the random errors are normally distributed; and (3) the random errors have homogenous (equal variance). In addition, descriptive statistics such as means and percentile characteristics were used to compare treatments means.

3. Results And Discussion

3.1. Model calibration and evaluation

3.1.1. Result of model calibration

The calibrated values of genetic coefficients for *BH-540* maize cultivar are depicted in Table 1. The results showed that the RMSE values for anthesis, physiological maturity, grain yield, aboveground biomass yield, and leaf area index (maximum) were 3 days, 4 days, 506 kg ha^{-1}, 1185 kg ha^{-1}, and 0.60, respectively with the nRMSE) values of 3.8%, 2.8%, 9.2%, and 7% and 15.8%, respectively (Table 2). There were strong agreements between the measured and the simulated values of leaf area index (LAI) with RMSE = 0.57, R^2 = 0.84 and d index = 0.93 that indicated strong agreement between the simulated and the observed values (Fig. 1). The result of model evaluation is discussed under section 3.1.2.

Table 1
Calibrated genetic coefficient of *BH-540* maize cultivar within the DSSAT model

Genetic parameters	Description	Genetic coefficients for *BH-540*
P1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8 deg. C) during which the plant is not responsive to changes in photoperiod.	245
P2	Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours).	0.60
P5	Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8 deg. C).	850.0
G2	Maximum possible number of kernels per plant.	780.0
G3	Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day).	8.5.0
PHINT	Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.	48.0

Table 2
Comparison between simulated and observed anthesis, physiological maturity, grain yield, aboveground biomass yield and leaf area index of *BH-540* maize cultivar during the model calibration at Tehuledere Wereda, Ethiopia

Crop parameters	Simulated	Measured	RMSE	nRMSE (%)
Anthsis (days)	83	80	3	3.80
Physiological maturity (days)	146	142	4	2.80
Grain yield at harvest (kg ha^{-1})	6006	5500	506	9.20
Biomass yield at harvest (kg ha^{-1})	18200	17015	1185	7.00
LAI (maximum)	4.40	3.80	0.60	15.80

3.1.2. Result of model evaluation

The performance of the CERES-maize model for simulating phenology, growth, and yield was evaluated by comparing the simulated and observed anthesis date, physiological maturity date, grain yield, and above-ground biomass yield (Fig. 2 and Fig. 3). The statistical analysis showed that the RMSE values for anthesis and physiological maturity dates were 2.53 days and 4.36 days, respectively with R^2 values = 0.72 and 0.88 and with d-index values = 0.87 and 0.80, respectively (Fig. 2). The RMSE, nRMSE, d-index and R^{-2} values for grain yield were 258.29 kg ha^{-1}, 4.7%, 0.88, and 0.94, respectively (Fig. 3).

Aboveground biomass yield also showed good agreement with RMSE = 1034.05, nRMSE = 10%, and d-index = 0.71 (Fig. 3). The results of model evaluation have shown that there were strong agreements between the simulated and the measured values. Thus, it can be concluded that the performance of the CERES-maize model to simulating phenology, growth and yield of maize was very good under environmental conditions of the semi-arid areas in Ethiopia. Therefore, the crop model can be used for assessing impact of projected climate change on maize production and to identify suitable management strategies under the present and future climate conditions of the study region.

3.2. Projected climate changes and its implication on maize production

3.2.1. Projected climate changes in the study region

Future climate projection in the study region showed that both mean annual maximum and mean annual minimum temperatures may increase by 2030s and 2050s under both RCP4.5 and RCP8.5 scenarios (Fig. 5). The projection result showed that mean annual maximum temperature may increase by 1.4°C and 1.5°C by 2030s under RCP 4.5 and RCP8.5 scenarios, respectively as compared to the baseline period. Projection for 2050s period also showed that mean annual maximum temperature may increase by 1.9°C and 2.5°C for the respective RCP scenarios. Likewise, mean annual minimum temperature may increase by about 1.4°C and 1.6°C by 2030s whereas it is projected to increase by 2°C and 2.5°C by 2050s under the respective RCP scenarios (Fig. 5). The projection result revealed that mean annual total rainfall may increase by about 4% and 5% by 2030s under RCP4.5 and RCP8.5, respectively whereas it may increase by 5% and 8% by 2050s under the respective scenarios (Fig. 5). The result of the projected climate changes in this study is in line with that of Conway and Schipper (2011), Setegn *et al.*(2011), and Dereje *et al.*(2012) who reported an increase in future temperature in the coming decades in Ethiopia. It can be concluded that the variations in these climate parameters could negatively affect crop production in the semiarid environments of northeastern Ethiopia.

3.2.2. Impact of projected climate change on maize phenology

Result of impact analysis of projected climate change on maize phenology (anthesis and physiological maturity) is depicted in Fig. 4. The result showed that both anthesis and physiological maturity dates of *BH-540* maize cultivar may significantly ($P < 0.05$) decrease in 2030s and 2050s under both RCP4.5 and RCP8.5 scenarios in relative to the simulated values for the baseline period (Fig. 4). Simulation at Tehuledere Wereda showed that maize anthesis date will likely decrease by 6% and 7% in 2030s and by 10% and 13% in 2050s under RCP4.5 and RCP8.5 scenarios, respectively (Fig. 4a). In the same way, physiological maturity may decrease by 8% and 10% in 2030s and by 12% and 15% in 2050s under the respective climate scenarios (Fig. 4a). The results at Kallu Wereda also showed similar trends. Maize anthesis date will likely decrease by 10.5% and 12.5% in 2030s and by 16% and 20% in 2050s under

RCP4.5 and RCP8.5 scenarios, respectively (Fig. 4b). Physiological maturity date may decrease by 13% and 17.6% in 2030s and by 19% and 21% in 2050s for the respective scenarios (Fig. 4b).

The highest reductions in anthesis and physiological maturity dates of maize were predicted in 2050s under RCP 8.5 scenario that could be attributed to the highest temperature that might accelerate the growth and development stages and shorten the crop growth period (Fig. 5). The reduction in phenological stages of maize under the future climate conditions may lead to yield reduction due to the reduction in growth period. High temperature may aggravate soil evaporation and transpiration rates and reduce water availability for the crop. Extreme weather conditions such as high rainfall under the projected climate change may cause soil erosion and reduce water and nutrients availability for the crop and affect nutrients uptake and water absorption by the maize crop. High temperature may also accelerate soil organic matter degradation and reduce water availability and nutrients retention capacity of the soil. All these conditions may lead to affect maize phenology in future climate conditions. In line with this result, Turner and Rao (2013) reported that days to anthesis and days to maturity of maize were reduced when the temperature was increased by about 1%. The study by Baviskar et al. (2017) also showed that increased temperature led to fast accumulation of heat units and forced the maize crop to flower and mature earlier. Thus, it can be generalized that future temperature may adversely affect maize production in 2030s and 2050s time periods which could lead to affect yield. Therefore, to reduce impact of future climate on maize production in the study region exploring suitable management practices are necessary for sustainable maize production in the study region.

3.2.3. Impact of projected climate change on maize yield

Change in grain yield and aboveground biomass yield of *BH-540* maize cultivar in 2030s and 2050s under RCP4.5 and RCP8.5 scenarios are depicted in Fig. 6a and 6b. The results at Tehuledere Wereda showed that grain yield may decrease by 11% and 20% in 2030s and by 26% and 29% in 2050s under RCP4.5 and RCP8.5 scenarios, respectively (Fig. 6a). Results at Kallu Wereda also showed that grain yield may decrease by 13% and 15% in 2030s and by 17% and 19% in 2050s for the respective scenarios (Fig. 6b). Above-ground biomass yields may also decrease by 4% in 2030 and by 4% and 5% in 2050s for the respective RCPs (Fig. 6a). Similar trend was observed at Kallu Wereda where aboveground biomass yield may decrease by 4.6% and 5.8% in 2030s and by 13% and 15% in 2050s for RCP4.5 and RCP8.5, respectively (Fig. 6b).

The overall prediction results showed that maize yield may negatively affected by the projected climate changes in 2030s and 2050s mainly due to high temperature. The increase in temperature in future climate may reduce water availability for the maize crop by accelerating water loss from the soil and plant (Fig. 7). Water availability may be reduced due to runoff that might be caused by intense rainfall (Fig. 7). High runoff could reduce water and nutrients availability required for the maize crop. Thus, water deficit and high temperature might be the major causes for maize yield reduction in the present and future climate conditions of the study region. The current maize yield under the farmers' management condition is very low and yield could be further reduced unless suitable adaptation measures are identified and implemented in these areas. This study concluded that best crop management practices are required to sustain maize productivity under the present and future climate conditions of the study area. Guo, *et al*. (2017) suggested that the major causes of maize yield reduction are global warming and reduced water availability. Previous studies have also shown that maize potential and attainable yield decreased by 8.0% from 1961 to 2009 mainly due to climate change (Lv, S. *et al*., 2014). A study by Seo et al. (2005) showed that global warming is very harmful to most crops that could lead to overall yield reduction due to the shortening of growing season. Niang et al., (2014) reported that the negative effect of climate change on crops may be aggravated by water deficit and outbreak of diseases, insects, and weeds. Maize production in the study region is rainfed. Thus, maize yield may significantly decrease under future climate conditions due to terminal water deficit caused by high temperature.

3.3. Effects of nitrogen and supplemental irrigation on maize grain yield

The statistical analysis showed that both the main effects of nitrogen and water regimes and their interactions significant ($p < 0.05$) affected maize grain yield at both site in 2030s and 2050s under both RCP4.5 and RCP8. 5 scenarios (Table 3 and Table 4). The highest simulated maize grain yield at Tehuledere and Kallu sites were predicted due to application of 138 kg N ha^{-1} under irrigated condition across the baseline climate, in 2030s and 2050s under both RCPs but it is statistically similar to the simulated yield due to the application of 92 kg N ha^{-1}. On the other hand, the lowest grain yields at both sites were simulated from the control treatment (0 kg N ha^{-1}) under non irrigated condition across time periods and RCP scenarios. In general, the simulation result showed that increasing nitrogen significantly increased maize grain yield under the rainfed and supplemental irrigated conditions across the present climate and future climate conditions. The yield response of the maize crop to nitrogen application indicated that both the sites are low nitrogen content (nitrogen deficiency) that significantly influence the maize crop. Although the highest simulated grain yield `was due to application of 138 kg N ha^{-1} under irrigated condition, the application of 92 kg N ha^{-1} can optimize maize grain yield in the study region. The result also indicated that strong synergetic effect of soil moisture and nitrogen availability to increase maize yield. Thus, maize yield may significantly increase by optimum application of nitrogen fertilizer and by using supplemental irrigation which could be applied at the flower initiation and grain filling stages of the maize crop (Table 3 and Table 4 and Fig. 8). The result of the current study also indicated that impact of water deficit will likely be the most prevalent constraint for maize production under present and future climate conditions of the study region if the water deficit occurs particularly during the sensitive growth stages of the maize crop. The significant yield response to nitrogen and supplemental irrigation suggest that the synergetic effect of nitrogen and irrigation was very high for increasing growth and yield of maize. As the study areas are located in the semi-arid region water is the most limiting factor for crop production. Rainfall in these areas is low in quantity and highly variable in distribution. Thus, application of limited amount of water during the critical stages of the maize crop will likely improve maize yield significantly in the present and future climates in the region. Water conservation practices are widely practices in the region. Hence, addition of limited amount of water during the critical growth stages of maize crop could significantly increase maize yield under the changing climate conditions of the study areas. A study by Liu, *et al.*(2016) showed that maize yield was significantly increased through the use of optimum fertilizers and using high-yielding crop varieties. A study by Li et al. (2020) also showed that water shortage and lower soil nitrogen may limit nitrogen uptake and its utilization by the crop. The present study suggests that three times application of 100 mm water in ten days interval starting the beginning the anthesis stage of maize crop with the application of 92 kg N ha^{-1} may optimize maize grain yield in the present and future climate conditions of the study region. In addition, evaluation of other crop management practices would be crucial for promoting sustainable maize production in the study region.

Table 3

Effects of nitrogen (kg ha^{-1}) and supplemental irrigation on grain yield (kg ha^{-1}) of *BH-540* maize cultivar at Tehuledere district, Ethiopia. RF and SI represent rainfed and supplemental irrigation, respectively.

Treatments		**20030s**		**2050s**	
	Baseline	**RCP4.5**	**RCP8.5**	**RCP4.5**	**RCP8.5**
0 N + RF	3619E	3452E	3444D	3267E	3377E
46 N + RF	4026D	4027D	3994C	3781D	3763D
92 N + RF	4282CD	4323CD	4363B	4085C	4062CD
138 N + RF	4416C	4485BC	4550B	4249C	4202BC
0 N + SI	4370CD	4020D	3958C	3624D	3804D
46 N + SI	5033B	4788B	4653B	4352C	4403B
92 N + SI	5525A	5379A	5224A	4809B	4825A
138 N + SI	5842A	5687A	5556A	5122A	5094A
LSD (0.05)	372	342	345	295.0	337.0

Means within a column followed by the same letter (s) are not significantly different at 5% probability level according to DMRT.

Table 4

Effects of nitrogen (kg ha^{-1}) and supplemental irrigation on grain yield (kg ha^{-1}) of *BH-540* maize cultivar at Kallu district, Ethiopia.. RF and SI represent rainfed and supplemental irrigation, respectively.

Treatments		20030s		2050s	
	Baseline	RCP4.5	RCP8.5	RCP4.5	RCP8.5
0 N + RF	3330E	3257E	3284E	3273E	3665E
46 N + RF	3730D	3805D	3655D	3702D	3524D
92 N + RF	3952D	4146CD	3889CD	3978CD	3767CD
138 N + RF	4068CD	4315C	3947CD	4073C	3924C
0 N + SI	4411C	43956D	4018C	3826CD	3694CD
46 N + SI	5064B	4761B	4572B	4458B	4269B
92 N + SI	5574A	5320A	5017A	4927A	4651A
138 N + SI	5933A	5578A	5242A	5126A	4919A
LSD (0.05)	390	342	345	303.0	329.0

Means within a column followed by the same letter (s) are not significantly different at 5% probability level according to DMRT.

4. Conclusion

The semi-arid areas in Ethiopia are dominated by crop-livestock farming system. Crop production is dominated by cereal crops. Drought occurs frequently in this region and affects the farming system. The late-onset and early offset of rainfall is the major constraint that affects crop production in the region. The rainfall variability and the low water holding capacity of the soil may expose maize crop to terminal water deficit. Maize is highly sensitive crop to water deficit and high temperature could be seriously affected by global warming. Thus, assessing impact of future climate change on maize production has paramount importance to develop suitable adaptation strategies for sustainable maize production in the region.

The CERES-maize model in DSSAT package was first calibrated and evaluated using data of phenology, growth and yield. Then, the calibrated model coupled with the seasonal analysis program in DSSAT were used to assess impact of projected climate change on maize production in 2030s and 2050s under RCP4.5 and RCP8.5 climate scenarios and also to identify suitable crop management strategies that sustain maize production in the study region.

The results of model calibration and evaluation showed that the model well simulated growth, development, and yield of maize cultivar *BH-540* as indicated by the strong agreements between the simulated and observed values. Thus, if properly calibrated, the crop models can be used to assess impact of climate change on crops production and to select suitable adaptation strategies. The results of impact analysis showed that maize yield may substantially decrease in 2030s and 2050s relative to yield of the baseline period. However, the application of optimum nitrogen fertilizer and supplemental irrigation may substantially increase maize productivity under the present and future climate conditions of the study areas. Thus, application of three irrigation with 100 mm water each in 10 days intervals starting the anthesis stage of the maize crop combined with 92 kg N ha^{-1} may be potential adaptation strategies to significantly increase maize yield across climate periods and RCP scenarios. However, more research has to be conducted to explore potential adaptation strategies that can sustain maize production in the region.

Declarations

Competing interest:

There are no competing of interest among the authors regarding this manuscript.

Authors Contribution:

The author Fikru Chekole was involved in executing the field experiment, data collection and data analysis, and also writing the manuscript. Dr Adem Mohammed was involved in data analysis and writing the manuscript. Jobair Alam and Prof. Benjamin Lamptey were involved in writing the manuscript.

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Figures

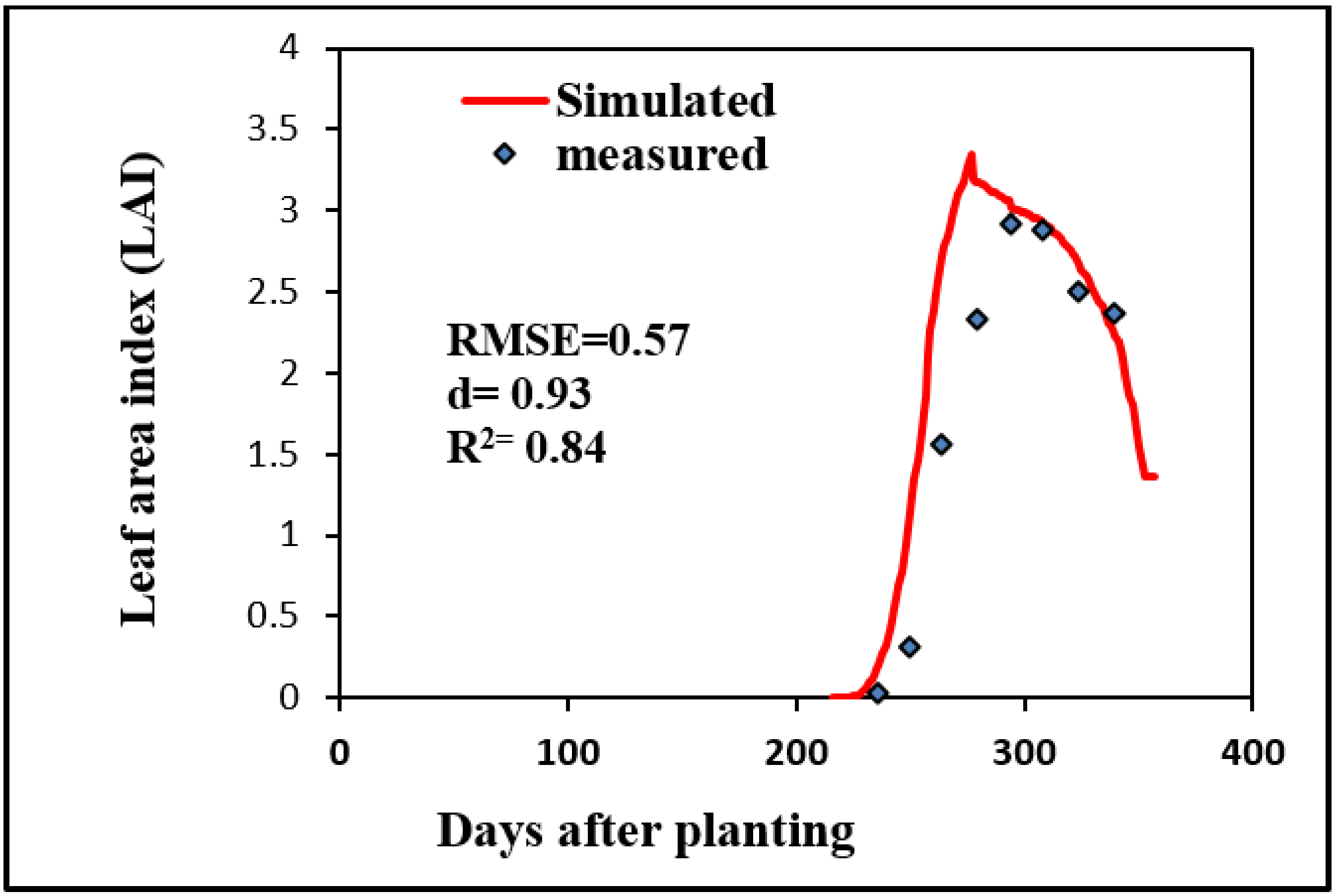


Figure 1

Comparison between simulated and measured leaf area index of maize cultivar during model calibration at Tehuledere district, Ethiopia

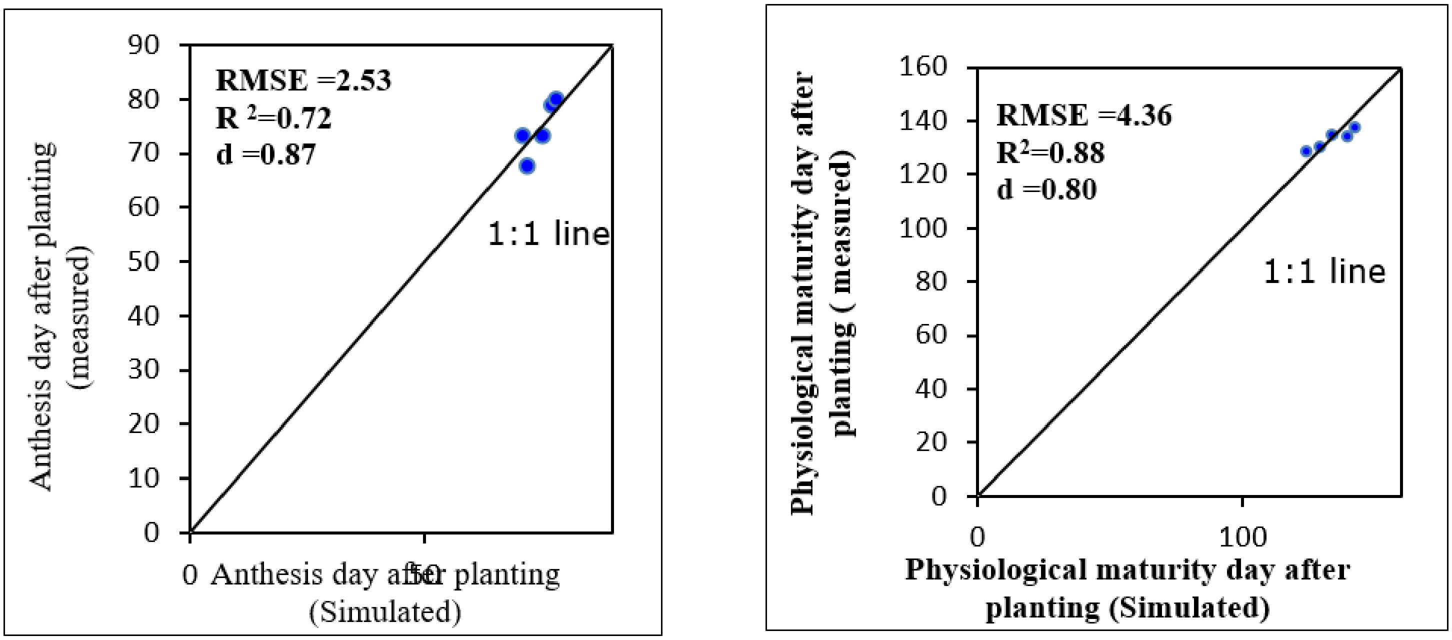


Figure 2

Comparison between simulated and observed anthesis date and physiological maturity date in 2013, 2014, 2015, 2016, and 2017 at Kallu district

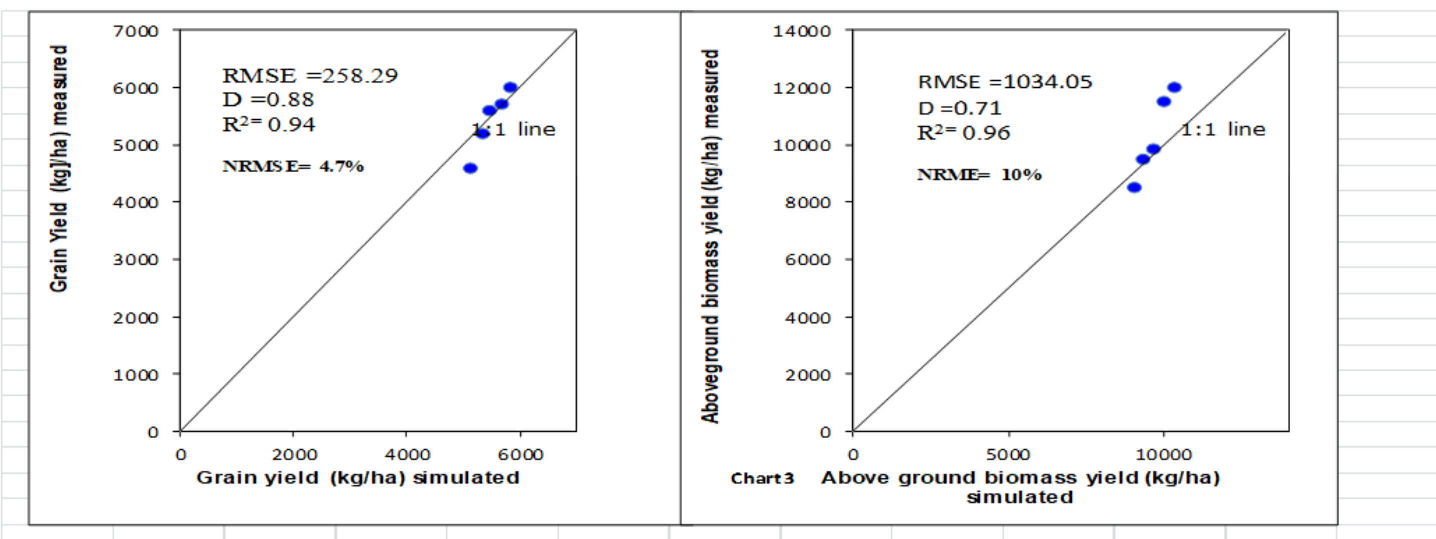
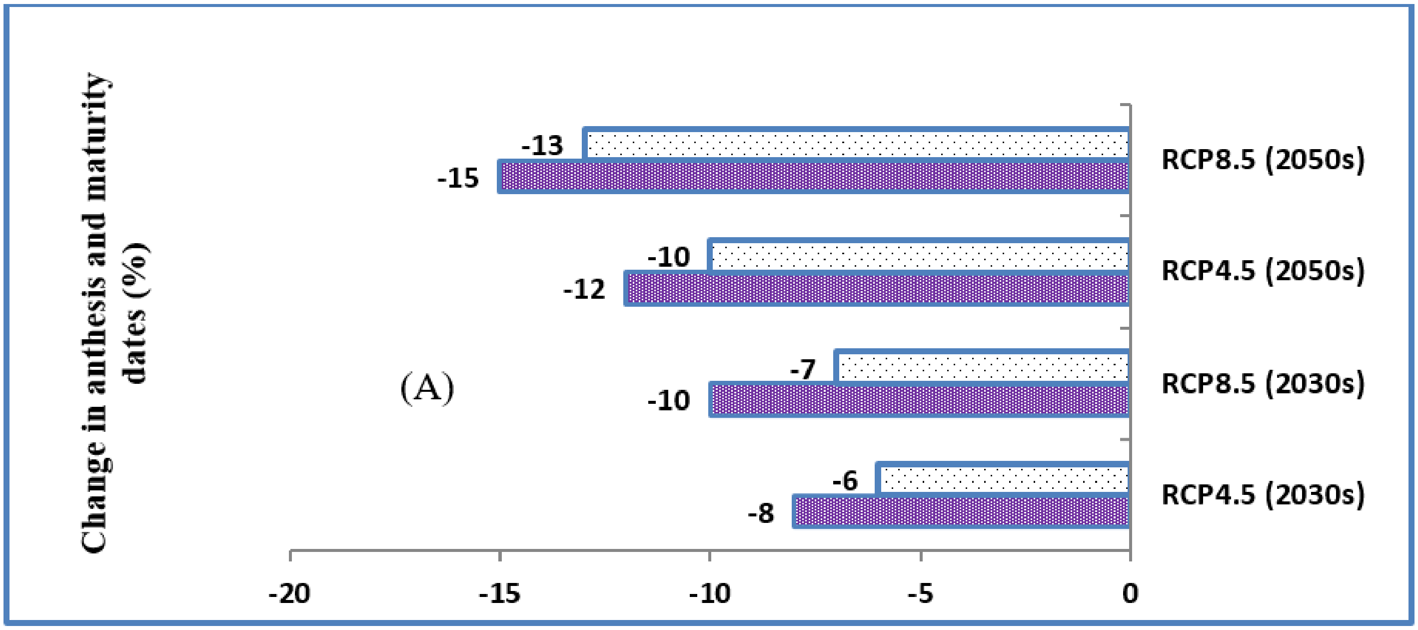


Figure 3

Comparison between simulated and observed grain yield and aboveground biomass yield in 2013, 2014, 2015, 2016, and 2017 at Kallu district



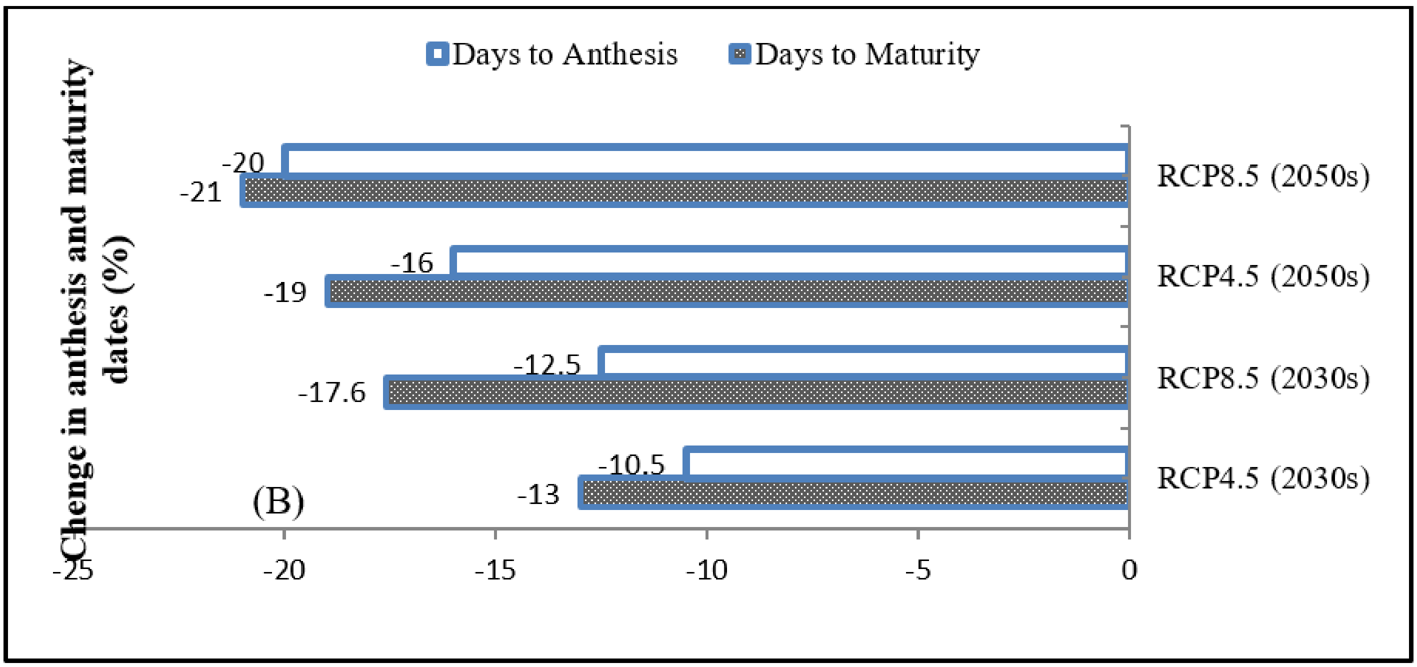


Figure 4

Change in anthesis and physiological maturity dates (%) of BH-540 maize cultivar in 2030s and 2050s under RCP4.5. and RCP8.5 scenarios in Tehuledere (A) and in Kallu (B), northeastern Ethiopia

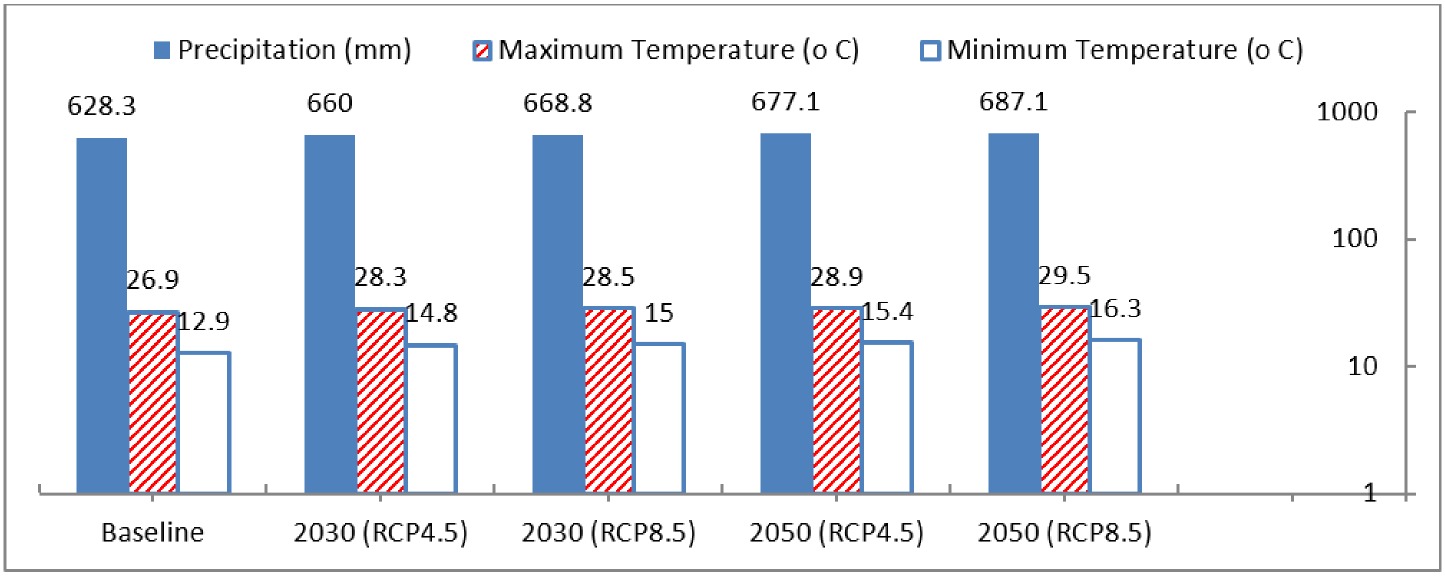


Figure 5

Model simulated total precipitation, mean maximum temperature and mean minimum temperature during the growing period of maize in the baseline, 2030s and 2050s under RCP4.5 and RCP8.5 scenarios in the study region

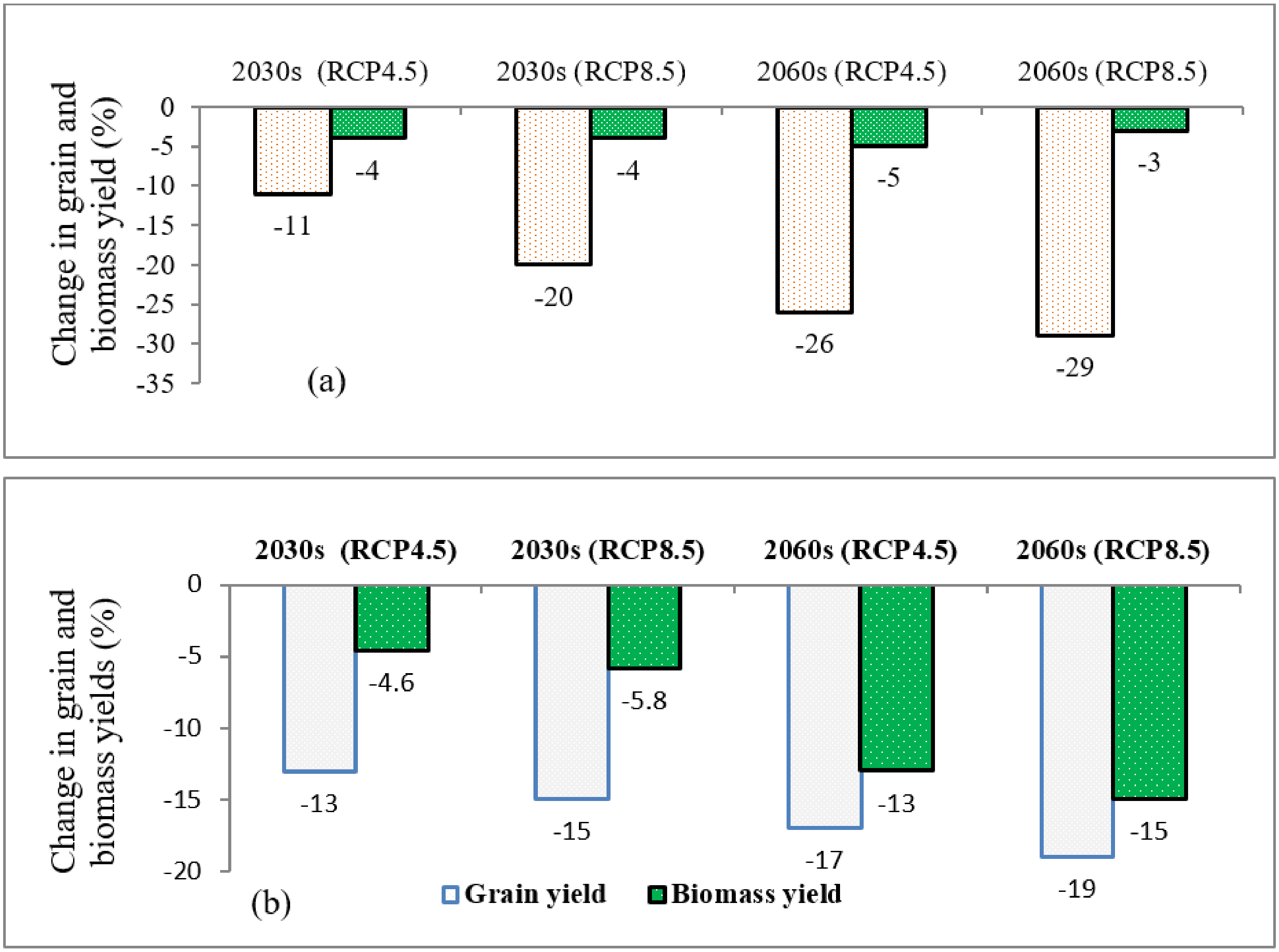


Figure 6

Change in grain yield (GY) and biomass yield (BM) of *BH-540* maize cultivar in 2030s and 2050s under RCP4.5 and RCP8.5 in Tehuledere Wereda (A) and Kallu Wereda (B), Ethiopia

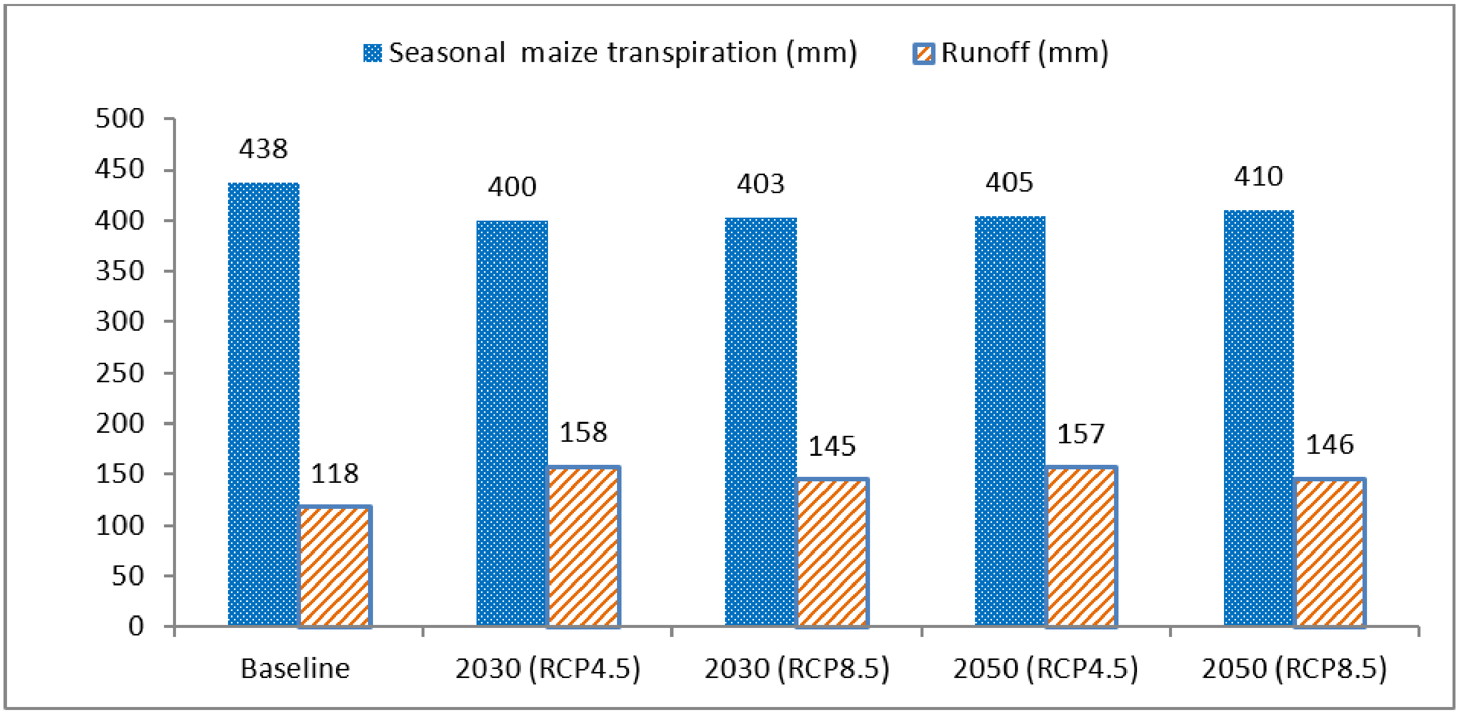


Figure 7

Effect of projected climate change on maize seasonal transpiration (mm) and runoff (mm) in the baseline period, 2030s and 2050s under RCP4.5 and RCP8.5 scenarios at Tehuledere Wereda, Ethiopia

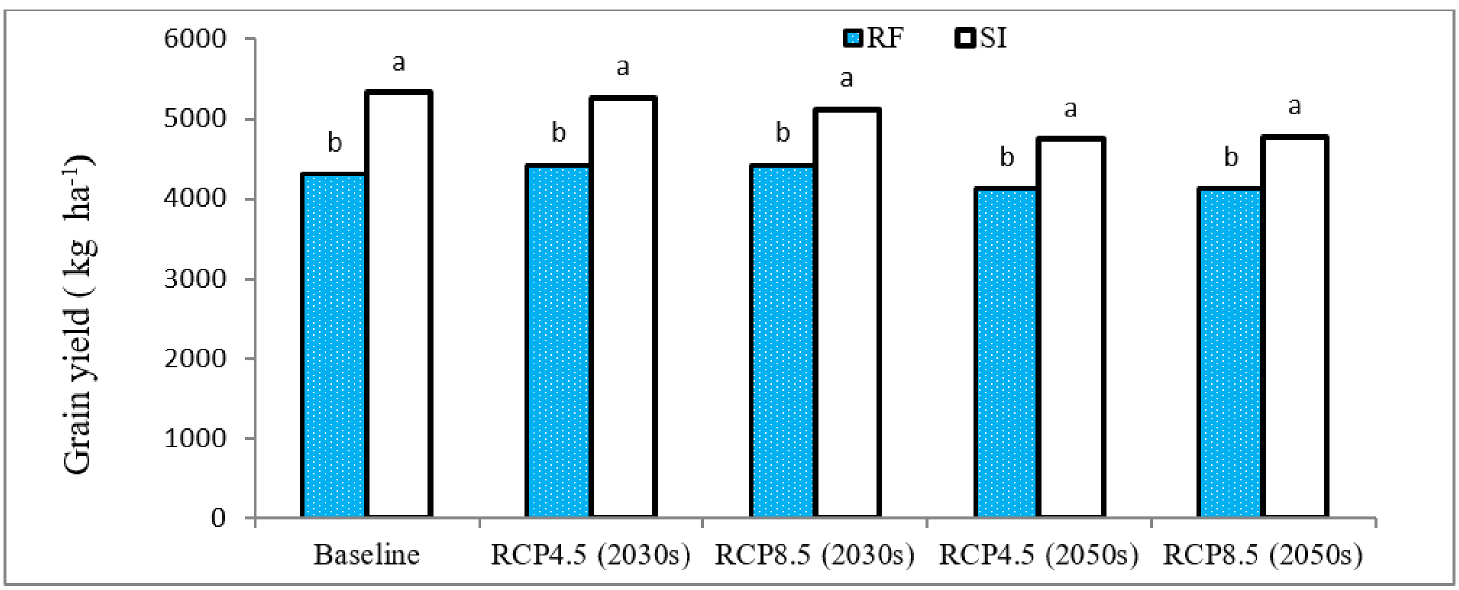


Figure 8

Effect of supplemental irrigation on mean grain yield of *BH-540* maize cultivar as compared to rainfed yield in the baseline, 2030s and 2050s under RCP4.5 and RCP8.5 scenarios. Letters *a* and *b* indicates significant difference at 5% probability level. *RF* and *SI* indicates rainfed and supplemental Irrigation, respectively