Modeling Impacts of Climate Change on Bread Wheat (Triticum Aestivum l.) Productivity in Bale Highlands, South Eastern Ethiopia: Case of Robe Area

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ABSTRACT

Wheat is one of the food security crops in Ethiopia which is critically sensitive to the impacts of climate change. However, the factors of climate change are very local; hence a local level and crop-specific understanding of the impact is extremely important. With this understanding, a study is conducted at Sinana district in Bale highlands to modeling the impacts of climate change on bread wheat production and analysis under future climate scenarios. Historical climate data (1984-2016), projected climate data downscaled using the ensemble of all GCMs, were analyzed to understand the local level climate change. The future climate is analyzed regarding of changes in annual rainfall, seasonal rainfall and monthly rainfall statistics using INSTAT v3.37 software analytical tools respectively. Observed agronomic and soil data were used to calibrate and validate the Crop model of Decision Support for Agrotechnology Transfer (DSSAT) model. The model was used to simulate the impact of future climate changes and variability in bread wheat yield of Madda walabu and Sofumer varieties at Sinana district in Bale highlands. The results revealed that climate change caused variability on bread wheat productivity in Sinana district within different time slices. There is a negative impact simulated at Robe area except in 2080's under RCP4.5 and 2050's and 2080's under RCP8.5 scenarios. Madda walabu yield is simulated to decreased up to -21.4% at Robe by 2050's under RCP4.5 scenario relative to the baseline due to climate change impacts. For Sofumer, an increase in grain yield from the baseline condition was 7.0 % and 11.6 % by near century (2030's) under both RCP4.5 and RCP8.5 scenarios respectively. Also, much yield reduction is experienced the 2050's and 2080's by 15.6 % and 27.0 % under RCP4.5. The decrease was expected by 21.9 % and 23.9 % in 2050's and 2080's under RCP8.5 respectively. Therefore; climate change had a severe impact that justifies the need for site-specific study. Therefore, future agricultural practices should benefit from agro weather advisory service for farming decision in study the area.

Key Words: climate change, impact, modeling, bread wheat

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INTRODUCTION

The climate change impacts on agriculture concerned worldwide and occurring more in developing countries, compared to developed countries (World Bank, 2012). There are numerous studies devoted to assessing the impacts of climate change on agricultural production over the past decades (Joshi *et al.*, 2011) and future (Liu *et al.*, 2013). Globally, temperature and rainfall are being altered differently from one region to another (IPCC, 2014). Scientific assessment reports proved that global average temperature would rise between 1.4 and 5.8°C by 2100 with the doubling of the CO_2 concentration in the atmosphere (Cubash *et al.*, 2001). The impacts of increased temperature from global warming and changes in rainfall patterns resulting from climate change are expected to reduce agricultural production and put further pressure on marginal land (Travis and Daniel, 2010; Beddington *et al.*, 2012; Valizadeh *et al.*, 2013). Thus the dependence of Ethiopia on agriculture makes its economy extremely vulnerable to the risks associated with climate variability and change. Therefore, climate variability and change are a serious concern for both researchers and development planners in Ethiopia. It is, therefore, essential to assess rainfall and temperature temporal variability over an area to quantify its effects especially on crop yields that could be translated into the best adaptation options to the development potential and specific challenges under a farming zone (Mishra *et al.*, 2013). Apart from the detailed analyses and quantification of past observational climate data, downscaled climate information from General Circulation Model (GCM) predictors is essential for vulnerability assessment and impact mapping against agricultural systems while enhancing our potential to adapt to the changes (Wilby *et al.*, 2004). Crop simulation modeling is one way through which the impacts of a variety of potential scenarios can be explored. Model-based climate change impact assessments are the statistical relationships between crop yield and phenological or environmental variables (Wang *et al.*, 2011). Wheat (*Triticum aestivum L.*) is one of the most important crops in the world regarding production and nutrition. Ethiopia is the largest producer of wheat in sub-Saharan Africa next to South Africa (De Brauw and Minot, 2016). Both durum and bread wheat are grown in Ethiopia (Bergh et al., 2012). Oromia accounts for over half of national wheat production 54 %, followed by Amhara 32 %; Southern Nations, Nationalities and Peoples (SNNP) 9 %; and Tigray 7 % (CSA, 2013). Of the current total wheat production area, about 75 percent is located in the Arsi, Bale and Shewa wheat belts (MOA, 2012). Seasonal and spatial wheat yield fluctuation due to climate and soil variability is a common phenomenon in Ethiopia (Muhe and Assefa, 2011). Bale highlands are the major wheat producing areas of Ethiopia and are deemed to be the wheat belts of East Africa (Bekele *et al.*, 2000). Changes in atmospheric composition and the physical climate, including temperature, rainfall and agronomic management of wheat, ultimately affecting wheat production and productivity in Bale highlands. The objectives of this study are to modeling the impacts of climate change on bread wheat productivity in the Bale highlands, Southeastern Ethiopia with climate taking into account and DSSAT cropping model simulates the development and yield of crop growing by based on 17 GCMs (General Climate Models) for three time slices under two Representative Concentration Pathways (RCP4.5 and RCP8.5) scenarios.

MATERIALS AND METHODS

General Description of the Study Area

The study was carried out at Robe station Sinana District, which is a part of highlands of Bale Zone, Southeastern Ethiopia located at 6^0 50′ N-$7^0$17′ N and 40^0 06′ E-$40^0$25′ E, 430 km southeast of Addis Ababa. Altitude ranges from 1700 to 3100 meters above sea level (m.a.s.l). Bale highlands are characterized by a bimodal rainfall pattern with total mean annual rainfall of 812.4 mm for Robe station. The area has bimodal rainfall distribution i.e. spring season (short rainy season) in the months of February to May and summer (the main rainfall season) extending from June to September. Spring receives about 19.5 mm to 106.5 mm at Robe station, whereas summer receives 64.6 mm to 120 mm at Robe station. The mean minimum, maximum and average of annual temperature of the Robe is 8.1 ^{0}C, 21.6 ^{0}C, and 14.9 ^{0}C respectively. The average air temperature in the spring season (February, March, April and May) was 14.9 ^{0}C Robe station whereas the main season which is called summer season the average air temperatures was about 15.6 ^{0}C at this station. The geology of Bale highlands consists of flood basalt belonging to the Arsi and Bale basalts of the Oligocene Miocene volcanic eruptions and rhyolite belonging to the Ghinir formation of the Quaternary volcanic eruption (Esayas and Ali, 2006). The identified three major soil types in this Zone were Phaeozems, Cambisols, and Vertisols

Model Input Data Sets

Climate data: The 33 years daily maximum and minimum temperatures, rainfall, as well as sunshine hour duration data are obtained from Sinana Agricultural Research Center (SARC) and National Meteorological Agency (NMA) of Ethiopia. The daily observed climate data is checked for quality and missing values and patched using Markov chain model of INSTAT v.3.37, scanning weatherman data DSSAT and special macros and graphics for automatic checking and data quality control.

Projection of Future Climate

Future climate over the Bale highlands was downscaled at Robe stations from ensembles of 17 GCMs (BCC-CSM1-1, BCC-CSM1-1-M, CSIRO-Mk3-6-0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, GISS-E2-H, GISS-E2-R, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MIROC-ESM-CHEM, MIROC5, MRI-CGCM3 and NorESM1-M) and RCP (representative concentration pathways) for time period centered around2030's, 2050's and 2080's predictors.

The ensembles of all 17 models a new feature of the updated GCM model are used for impact during analysis. RCPs new scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) in Fifth Assessment Report (AR5) are applied for emission scenario. To predict future precipitation and temperature, the medium range emission scenario (RCP4.5) and very high emission scenario (RCP8.5) were used in the present study using a web-based software tool marksim online software http://gisweb.ciat.cgiar.org/MarkSimGCM/MarkSim web version for IPCC AR5 data (CMIP5). The Representative Concentration Pathways (RCPs), which are used for making projections based on these factors, describe four different 21st-century pathways of GHG emissions. MarkSim GCMs is a spatially explicit daily weather generator that uses third-order Markov chain climate simulator that was found to be suitable for tropical countries like Ethiopia (Jones and Thornton, 2013). Moreover it does not depend on long-term climate data and does not need recalibration, as it is already calibrated (Jones and Thornton, 2003). MarkSim GCMs require geographical coordinates (latitude and longitude of the specific station) and station name to downscale and generate future daily data of a given site. The Model is linked with Google earth to indicate the place which is being dealt with and has options to use different types of MarkSim GCMs. In this study, the average ensemble of all the GCMs and scenarios of RCPs (RCP4.5 and RCP8.5) were downscaled to generate the climate variables from 2020-2095 for Robe station. As a final product of downscaling ensembles of all GCM daily climate data are produced for this study. The downscaled future data of all GCMs climate data were used to examine monthly patterns and the general trend of annual rainfall, seasonal rainfall, and average annual and seasonal for minimum and maximum temperatures of the study areas for future (2020-2095) periods by averaging the independent ensemble data.

Soil

The dominant soil of the Robe areas was showed with different depth in Table 1. These data are received from Sinana Agricultural Research Center (SARC) research output soil laboratory reported as terminal, annual and published documents (Esayas and Ali, 2006) to start the model application with different physical and chemical soil properties of the Sinana and Robe sites.

Table 1: Physical and chemical soil properties of the study area

	Soil Depth (cm) at Robe				
Parameters	0-30	31-60	61-90	91-120	121-200
pH(H_2O)	7.3	8.6	8.5	8.5	8.5
EC(ds/m)	0.031	0.026	0.033	0.037	0.047
Sand Soil (%)	21	27	29	24	23
Silt Soil (%)	30	36	33	35	32
Clay Soil (%)	49	37	38	41	45
Texture Class	C	CL	CL	C	C
CEC (meq/100g soil)	56	53	52	45.8	44.4
Base Saturation (%)	73	84	81	91	80
T.N (%)	0.133	0.12	0.091	0.052	0.059
Organic carbon (%)	1.995	1.397	1.177	0.399	0.379
DUL	0.495	0.409	0.397	0.378	0.389
LL	0.325	0.249	0.248	0.242	0.259
F.C (%)	43.5	39.9	42.7	46.96	52.46
P.W.P (%)	36.7	39.6	41.7	25.35	30.36
Bulk density (g/cm3)	1.17	1.24	1.29	1.34	1.34

Description of wheat varieties and management

The crop management data include variety; date of planting and emergence, planting method, plant distribution (row or broadcast), plant population at seedling and appearance, row spacing and planting depth is used. Crop genetic coefficients included in the model relates to photoperiod sensitivity (thermal time), duration and rate of grain filling, conversion of mass to grain number and vernalization requirements (Ritchie *et al.*, 1998). This study was focused mainly on bread wheat (Triticum Aestivum L) which is cultivated in Ethiopia. Varieties those were most popular for farmers, high yielding, good grain quality planted every year and had historical data at Robe 10 years were selected. Accordingly, Madda walabu and Sofumer are used in this study. Available time series wheat yield (kg/ha) data from 2006-2015 is obtained from Sinana Agricultural Research Center (SARC) for the varieties. Farm sites, rain-fed experiments were conducted by Sinana Agricultural Research Center (SARC) in Sinana district since in 2006 cropping season. The two varieties of bread wheat are grown in the study area. General cultivar information and experimental data on phenology and yield components are presented in Tables 4. Both Madda-walabu and Sofumer were resistant to rust diseases and Madda walabu was more yielder when compared with Sofumer and others varieties (SARC, 2003). For the model calibration, the treatments with the recommended fertilizer rates, i.e. 50 kg/ha urea and 100 kg/ha Di-ammonium Phosphate are used.

Table 2: General information of both bread wheat varieties (SARC, 2003)

Agronomic recommended of varieties	Madda walabu	Sofumer
Adaptation of Altitude (a.s.l.) in meter	2200-2600	2300-2600
Rainfall (mm) required	400- 950	400-950
Average days from Planting to Anthesis	76	73
Average days from Planting to Maturity	136	134
Plant height (cm)	95	97
Urea fertilizer rate (kg/ha)	50	50
DAP fertilizer rate (kg/ha)	100	100
Seed rate (kg/ha)	150	150
Actual yield (q/ha)	29-43	23-38
Year of release	2000	2000
Origin	SARC	SARC

The DSSAT Model Evaluation

Calibration: Model calibration is conducted by comparing the simulated values of development and growth characteristics of the variety with its corresponding observed values, and by calculating statistical parameters of an agreement between simulated and observed values. In this study, wheat experiment data conducted during the season of 206-2011 were used to calibrate the CERES-Wheat models at Robe. Daily data on solar radiation, maximum and minimum air temperature and rainfall for the same period is used for simulation. Soil data is obtained from the SARC soil laboratory report, research output and published documents. The resulting data were used as an input for DSSAT to generate crop yields for three-time slices centered in the 2030's, 2050's and 2080's.

Validation: The performance of the model in was validated using an independent data obtained from field experiment during the cropping seasons of 2012-2015 years at Robe. For this study the data were used for model evaluation; days to anthesis, days to maturity and harvested yield which collected over time. The RMSE, RMSEn and the index of agreement (d) are used for evaluating the goodness of fit.

Assessment of the Impact of Climate on Wheat Production

Crop yield simulation: Crop simulation modeling is one way through which the impacts of a variety of potential scenarios are explored. For comparison purpose, the model was used to simulate yield of both crop varieties, and the average yield is used as baseline data. Finally, the performance of both wheat varieties with the prescribed changes was compared with the baseline as follows.

$$\Delta \text{Yield} = \frac{\text{Ypredicted} - \text{Ybase} * 100}{\text{Ybase}} \qquad (19)$$

Where Y-predicted is predicted the yield (kg/ ha), Y-base is yield of the base period (kg/ ha), and Δ-yield is the yield difference (%).

RESULTS AND DISCUSSION

Impact Assessment of future climate on wheat production Using DSSAT Model

Model Calibration Performance: The model was run first to fix the genetic coefficients (cultivar parameters) that influence physiological parameters. The GenCalc program of (DSSAT version 4.6) was used to estimate the cultivar coefficients of the wheat cultivar. The GenCalc is software used for the calculation of cultivar coefficients for use in many crop models (Hunt et al., 1993) including the CERES-wheat model, which has seven cultivar coefficients that explain growth and development of a wheat cultivar. The program runs for phenology coefficients (P1V, P1D, and P5) and then runs for growth coefficients (G1, G2, G3 and PHINT). Then, the varieties of parameters that control Anthesis, maturity, and yield component are set in that order. The generated genetic coefficient would somewhat simulate for conditions of wheat productivity under the recommended management practice options for Madda walabu and Sofumer varieties Robe. The values for each coefficient and the two varieties were shown in (Table 3).

Table 1: Genetic coefficients used to calibrate and validate the CERES-Wheat model for simulation of Wheat varieties Madda walabu and Sofumer the study area.

Symbols	Definitions	Coefficients at Robe	
		Mw	Sf
P1V	Days, Optimum vernalizing temperature, required for vernalization	33.00	55.00
P1D	Photoperiod response (% reduction in rate/10h drop in pp)	91.30	110.0
P5	Grain filling (excluding lag) phase duration (°C.d)	618.0	720.0
G1	Kernel number per unit canopy weight at anthesis (#/g)	15	25
G2	Standard kernel size under optimum condition (mg)	44	30
G3	Standard non-stressed mature tiller wt (incl grain) (g dwt)	3.2	2.0
PHINT	Interval between successive tip appearance (°C.d)	100	95

Note: Mw; Madda walabu, Sf; Sofumer, Min; Minima, Max; Maximum, dwt; dry weight

Performance of CERES model in simulating yield-Madda walabu variety

Model calibration is conducted by comparing the simulated values of development and growth characteristics of each variety with their corresponding observed values, and by calculating statistical parameters of an agreement between simulated and observed values. The model performance was evaluated based on several year phenological and yield data collected at the respective research sites. Site-specific soil, climate, and management information were also used as data inputs in the model when evaluating the simulation performance of the model.

During the model evaluation, the result showed good performance of the CERES-Wheat model in simulating days to anthesis, days to physiological maturity and grain yield (Table 4). The specific crop model CERES-Wheat embedded in the DSSAT model was able to simulate most of the phenological stages and yield of wheat with reasonable accuracy. The model explained about 97 %, 93 % and 72% at Robe the variation between observed and simulated days to anthesis, days to maturity and yield respectively. The model simulated the actual days to maturity, days to flowering and yield with high precision is also indicated by the high R2 values, RMSE, CV, and d-statistics.

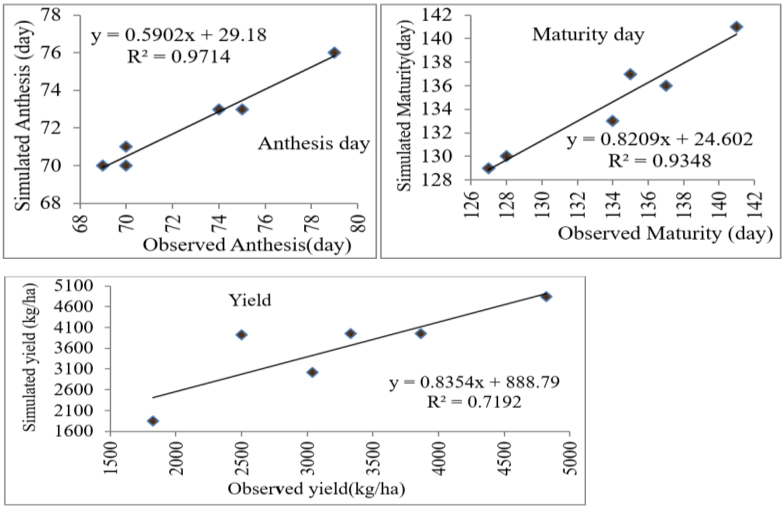

Figure 1: Observed and simulated results for Days to Anthesis, Days to physiological Maturity and Grain Yield harvested for Madda walabu variety.

Performance of CERES model in simulating yield -Sofumer variety

Similarly, for Sofumer, the model was able to simulate most of the parameters with reasonable accuracy. Therefore, simulated results showed that about 78.91 %, 82.60 % and 82.97% the variation in observed and simulated days to anthesis, days to maturity and grain yield respectively was captured by the model at Robe for Sofumer variety (Figure 2).

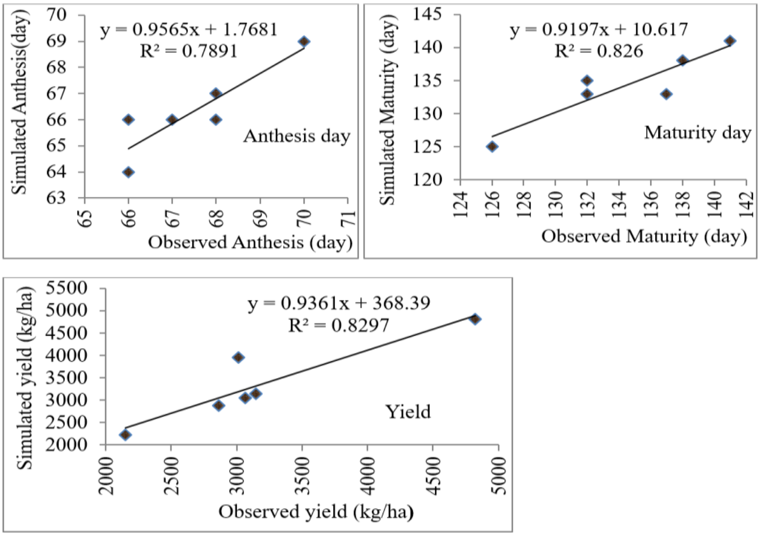

Figure 2: The observed and simulated results for Days to Anthesis, Days to physiological Maturity and Yield harvested for Sofumer variety.

The observed yield is satisfactorily simulated by the model for both varieties at both sites with an index of agreement (d) of 0.99; Root Means of Square Error (RMSE) of 633.6 kg/ha and 383.1 kg/ha for Madda walabu and Sofumer varieties at Robe. The phenology for the respective varieties was also well simulated by the model with an index of agreement (d) value of 0.98 and 0.97 and RMSE values of 1.63 and 1.35 days for anthesis for Madda walabu and Sofumer varieties at Robe respectively (Table 4). Additionally, the results indicated with an index of agreement (d) of 0.99 and 0.99 and RMSE of 1.5 and 2.12 days for maturity for Madda walabu and Sofumer varieties at Robe respectively.

The simulated values of RMSEn with days for anthesis and days for maturity showed excellent performance normalized root mean square error (RMSEn <10%), except yield result, indicated good performance (RMSEn 10–20%) in both wheat varieties. Hence, it also is seen with high precision as indicated by the high R2 values. Therefore, the model agreement is also demonstrated by the good d-statistics, RMSE, RMSEn, CV and R2 values. The simulation is considered excellent with RMSEn <10%, good if 10–20%, fair if 20–30%, and poor >30% for yield and yield components (Harb et al., 2016). Therefore, of the calibrated wheat models in DSSAT could reasonably be used to predict the impact of changing the climate.

Model validation performance

The performance of the model in both varieties was validated using agronomic data obtained from Sinana Agricultural Research Center (SARC) field experiment during the main rainy (Summer) season for the period of 2006-2015 at Robe. Model validation statistics were presented for Madda walabu and Sofumer bread wheat varieties at Robe areas in Table 5. Model evaluation is showed good performance of the CERES-wheat model in simulating days to anthesis, days to maturity and grain yields. Thus, it could be used studying the impact of future climate on the productivity of Madda walabu and Sofumer in the study areas.

During of the model validation, observed yield is satisfactorily simulated by the model for both varieties at both sites with an index of agreement (d) of 0.98 and 0.96; Root Means of Square Error (RMSE) of 11.7 kg/ha and 307 kg/ha; normalized root mean square error of 9.1% and 8.45% for Madda walabu and Sofumer respectively at Robe. The simulated by the model with d, RMSE, and RMSEn values of days for anthesis, and days for maturity were indicated a good performance for Madda walabu and Sofumer at Sinana and Robe areas (Table 5).

Table 2: Mean comparison of simulated and observed some parameters during model calibration

	Wheat Varieties at Robe											
	Madda walabu						Sofumer					
Parameters	Obs.	Sim.	RMSE	RMSEn	R^2	d-stat	Obs.	Sim.	RMSE	RMSEn	R^2	d-stat
DA(days)	72.8	72.2	1.63	2.24	0.97	0.98	67.5	66.3	1.35	2.01	0.79	0.97
DM(days)	133.7	134.3	1.53	1.14	0.94	0.99	134.3	134.2	2.12	1.58	0.83	0.99
Yield(kg/ha)	3230	3587	633.6	19.61	0.72	0.99	3177	3343	383.1	12.01	0.83	0.99

Table 3: Mean comparison of simulated and observed some parameters during model validation

	Wheat Varieties at Robe											
	Madda walabu						Sofumer					
Parameters	Obs.	Sim.	RMSE	RMSEn	R^2	d-stat	Obs.	Sim.	RMSE	RMSEn	R^2	d-stat
DA(days)	66.3	68.8	2.74	0.08	0.89	0.96	66.5	68.8	2.4	3.67	0.85	0.92
DM(days)	133	134	2.12	1.79	0.87	0.99	138	136	2.1	3.59	0.67	0.87
Yield(kg/ha)	3388	3421	11.7	9.10	0.98	0.99	3447	3434	307	8.49	0.78	0.96

Note: Obs. = observed values; Sim= simulated values; DA= days to anthesis; DM= days to maturity

Wheat yield response under future climate scenario

Climate change induced future yield variations were considerably high compared with the simulated baseline yield. The percent of yield changes were high for Madda walabu and Sofumer varieties are expected in all future climate scenarios (Figures 3-4). The projected future climate has an increased in yield of Madda walabu variety at Robe by near century (2030's) and mid-century (the 2050's) under RCP4.5 scenario whereas yield decrease is simulated for all reference periods with RCP8.5 (Figure 3). For Madda walabu, an increasing of yield under selected scenarios from the baseline condition and the variation of yield ranged between 2.4 % and 10.5 % by near century and mid-century under RCP4.5 at Robe area.

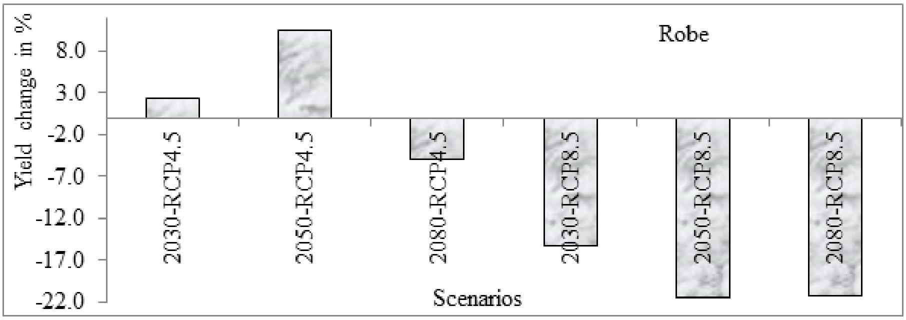

Figure 3: Projected yield Change in percentage from baseline under RCP4.5 and RCP8.5 for Madda walabu variety

A positive impact was simulated on Sofumer yield by near century (2030's) under both RCPs while revealed negative impact for the mid-century (2050's) and end century (2080's) under both RCP scenarios. The two varieties had responded differently for future climate change. For Sofumer, an increase in grain yield from the baseline condition for Sofumer variety at Robe was 7.0 % and 11.6 % by near century (2030's) under both RCP4.5 and RCP8.5 scenarios respectively. There was a decrease in yield from the baseline in 2050's and 2080's by 15.6 % and 27.0 % under RCP4.5 at Robe area. The reduction was expected by 21.9 % and 23.9 % at Robe in the 2050's and 2080's under RCP8.5 respectively.

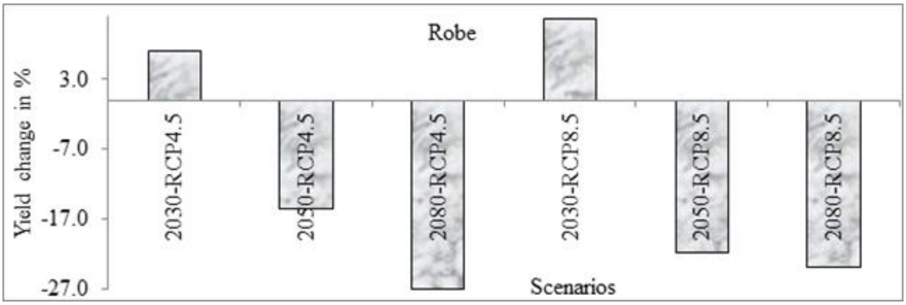

Figure 4: Projected yield Change in percentage from baseline under RCP4.5 and RCP8.5 for Sofumer variety

Generally, it is expected that there was high yield loss in the future climate scenario for Madda walabu variety at Robe site in both RCPs. This might be due to the impact of rainfall variation during the main cropping season (late onset, early cessation, moisture stress) and other associated hazards with rainfall and temperature change over the study sites. Therefore, improved crop management options may have a positive impact to increased yield towards its potential of production under changing the climate.

Wheat yield variability under future climate scenario

For Madda walabu, the maximum yield was expected 3892 kg/ha by mid-century (2050's) followed 3605 kg/ha by near century (2030's) for under RCP4.5 scenario at Robe area. Figure 5 shown projected yield variation for Madda walabu due to the impact of future climate variability at Robe under the two RCPs scenarios by near century (2030's), mid-century (2050's) and end century (2080's). The results had been depicted in box plot using a mean of simulated grain yield. Compared with baseline yield, only by near century (2030's) and mid-century (2050's) under RCP4.5 scenario was expected yield increased while shown decreased yields by end century (2080's) under RCP4.5 scenario and near century (2030's), mid-century (2050's) and end century (2080's) under RCP8.5 scenario for projected future climate variability. The lowest mean 2473 kg/ha of yields were expected by end century (2080's) under the RCP8.5 scenario at Robe area.

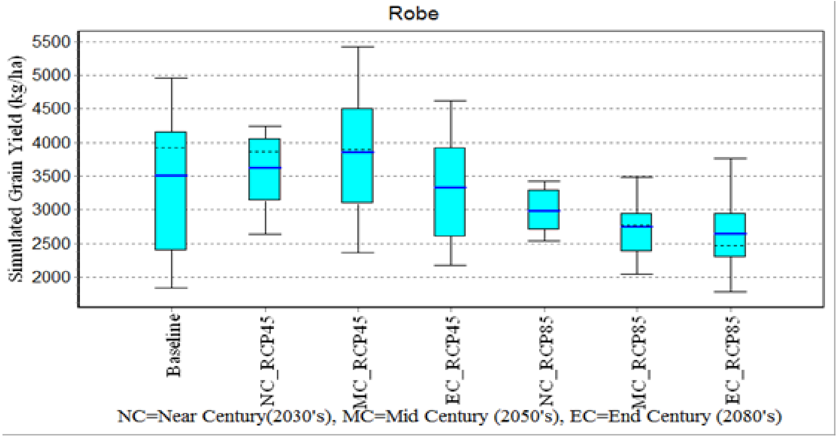

Figure 5: Box plot and whiskers, indicating the variation of projected grain yield of Madda walabu at Robe areas under different scenarios

For Sofumer, the highest yield mean could be observed at 3629 kg/ha and 3784 kg/ha by near century (2030's) under RCP4.5 and RCP8.5 scenarios at study area respectively. Projected yields variation for Sofumer due to the impact of future climate variability at Robe under the two RCPs scenarios by near century (2030's), mid-century (2050's) and end century (2080's) were indicated (Figure 6).

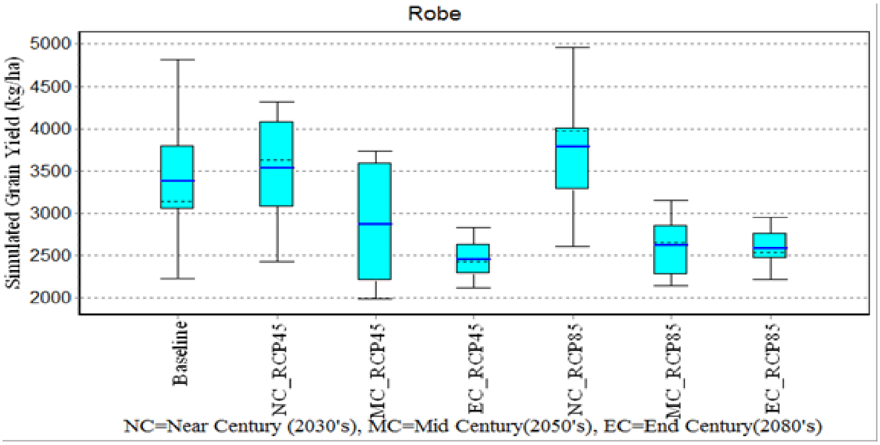

Figure 6: Box plot and whiskers, indicating the variation of projected grain yield of Sofumer at Sinana and Robe areas under different scenarios

The results had been depicted in box plot using the mean of simulated grain yield. Compared with baseline yield, the study area revealed decreased yields was expected by mid-century (2050's) and end century (2080's) under both RCP4.5 and RCP8.5 for projected future climate variability. Hence, the lowest mean 2476 kg/ha of yields were expected by end century (2080's) under RCP4.5 scenario at Sinana and Robe respectively. The highest yield variability was expected by mid-century (2050's) under RCP4.5 at Robe area.

CONCLUSIONS

Climate change was believed to cause the most damaging impacts on agricultural practices in developing countries like Ethiopia. In Ethiopia, climate change forms a serious concern because the country's economy was almost completely dependent on rain-fed agriculture which was the most vulnerable agricultural sector. This study showed that the negative impact of climate change was expected in future climate scenarios on bread wheat productivity in the Bale highlands, specifically at Sinana district. Hence, future research should introduce climate-smart agronomic practices to minimize the negative impact. Therefore, in the future, more research had to carry out for assessing alternative adaptation strategies to improve expected negative yield for these areas for who produce a wheat crop in the future. Thus, there was a need for sustained integrated research to overcome the impacts of climate change and variability, especially at the district and farm levels.

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