International Journal of Atmospheric and Oceanic Sciences
2017; 1(1): 14-20
http://www.sciencepublishinggroup.com/j/ijaos
doi: 10.11648/j.ijaos.20170101.13

Maize (Zea Mays L.) Productivity in Moist Mid-Highlands of Ethiopia Under Projected Climate Change: A Case Study of Ambo District

Fikadu Getachew*, Mezgebu Getnet, Robel Takele, Eshetu Zewdu

Climate and Geospatial Research Directorate, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia

Email address:
fikeget@gmail.com (F. Getachew)
*Corresponding author

To cite this article:
Fikadu Getachew, Mezgebu Getnet, Robel Takele, Eshetu Zewdu. Maize (Zea Mays L.) Productivity in Moist Mid-Highlands of Ethiopia Under Projected Climate Change: A Case Study of Ambo District. *International Journal of Atmospheric and Oceanic Sciences.* Vol. 1, No. 1, 2017, pp. 14-20. doi: 10.11648/j.ijaos.20170101.13

Received: December 22, 2016; **Accepted**: January 18, 2017; **Published**: February 27, 2017

Abstract: Decision Support System for Agrotechnology Transfer (DSSAT) was calibrated and evaluated to simulate maize (zea mays L.) var. BH660 under current and future climate in Ethiopia under moist mid-highlands of Ethiopia around Ambo Zuria district. Simulations for both current and future periods were run assuming present technology, current varieties and current agronomy packages to investigate rain-fed Maize yield responses. Simulations was made using downscaled weather data from five General Circulation Models (GCMs) under the Coupled Model Inter-comparison Project phase 5 (CMIP5) and two Representative Concentration Pathway (RCP 4.5 and 8.5) by mid-century show a mixture of increase and decrease in median Maize yields. Five GCMs project yields to increase by 5% - 23.0% and one GCM show a decrease by 2% - 9%. Model simulations under the remaining three GCMs give contrasting results of increase and decrease.

Keywords: BH660, Climate Change, DSSAT, Ethiopia, Maize and RCPs

1. Introduction

It has been mentioned in many literatures that climate change nowadays was flagged as a future fear for the human being the survival as it was appealed to tremendous impact on food security [8, 14]. In relation to this, the warmer and drier regions are expected overwhelmed by exacerbated impacts of climate change [21, 22]. In developing countries like Ethiopia, climate related risks remains as major challenge to agricultural production [1, 2, 6, 9]. There is also an emerging consensus that Eastern Africa, and particularly Ethiopia, is one of the most vulnerable regions regarding the impacts of climate variability and change [3, 4, 20, 23]. Several studies on precipitation and temperature change have indicated that the African continent is now warmer than it was 100 years ago and the rainfall exhibits higher inter-annual and intra-seasonal variability [3, 4, 5, 7, 19]. Climate variability over the last three decades of the 20^{th} century resulted in droughts and famine in several African countries [6, 10]. However, the magnitude and scale of the impacts of climate change and variability will not be the same in all agro-ecologies. In the same manner, the impacts of this climate change and variability would not be the same in all crops and crop cultivars. It is not also expected the response of those all crops and crop cultivars to the threat of climate change and variability in a similar manner.

In this study we attempt to assess the impact of climate change on maize yield taking into account major maize cultivar from semi-arid and sub-humid regions of Ethiopia whose genetic coefficients calibrated and validated in DSSAT (Decision Support System for Agro-technology Transfer) [12] with the help of experimental crop data along with site specific climate, soil and management information. The objectives of this study are to assess the impacts of climate change on maize productivity in the moist mid-highlands of Ethiopia around Ambo Zuria district by taking into account climate simulations based selected five GCM (General Climate Models) for two time periods under two Representative Concentration Pathways (RCPs).

2. Data and Methodology

2.1. Location and Climate of the Study Area

This study was conducted over Ambo Zuria district which is located in north eastern part of Oromia Regional State of Ethiopia (37° 52' to 38° 18' N, 9° 38' to 10° 19' E; see Figure 1). As it can be observed on figure 3 The total land area of the study area is about 281741.7 km^2, with the annual average precipitation varying from 474 mm in worst year (1983) to 1301 mm best year (1996) (see figure 1 and 2).

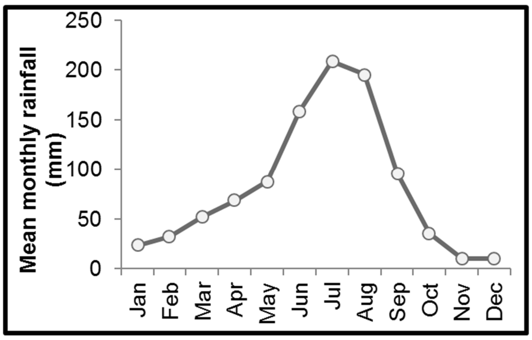

Figure 1. *Mean monthly rainfall (mm) ambo zuria.*

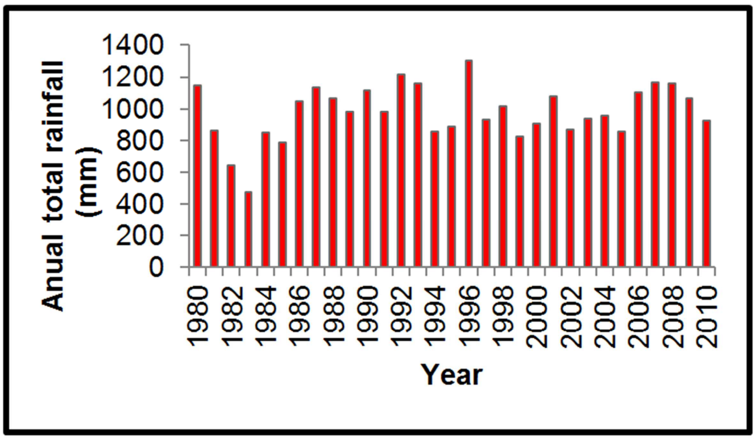

Figure 2. *Annual total rainfall (mm) of Ambo zuria.*

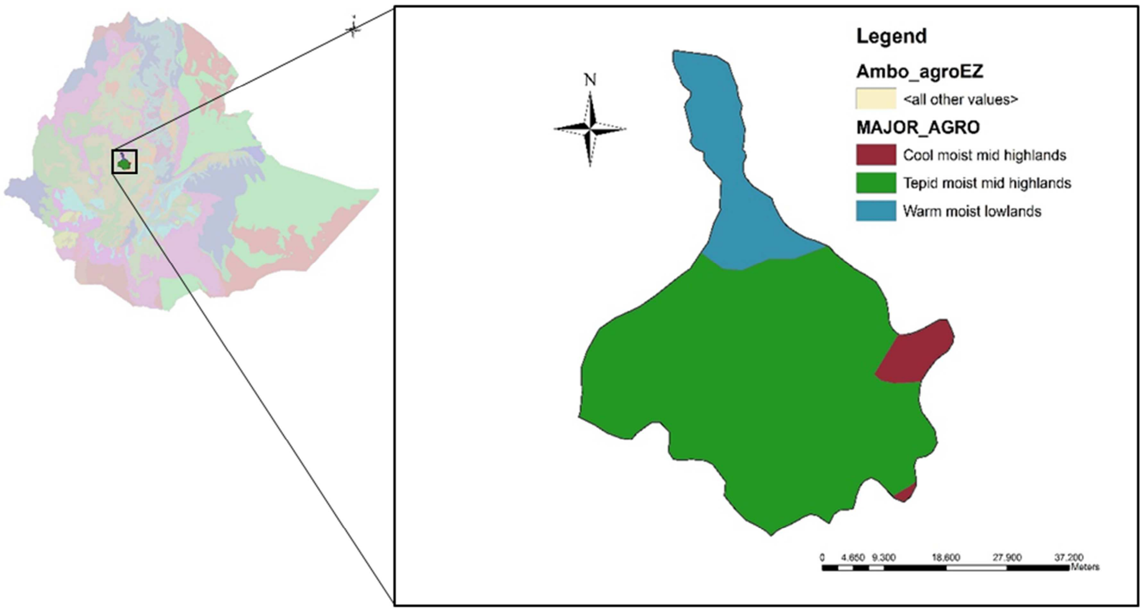

Figure 3. *Agro-ecology of the study area.*

2.2. Data

Observed precipitation, temperature and solar radiation data were collected from Ethiopian Institute of Agricultural Research (EIAR). The maize phenological data of ten years (2002-2011) was collected from Ambo Plant Protection Research Centre. While Global Circulation Models (GCMs) data of rainfall and temperature for the study area were downloaded from CMIP5 data portal for four time-slices centered around 1990, 2020, 2050 and 2080. The soils of this study area are Lithic Leptosols.

Soil physical and chemical characteristics of this study area are presented in Table 1.

Table 1. *Soil physical and chemical characteristics of Ambo areas.*

Depth (cm)	DUL (mm^3/mm^3)	DLL (mm^3/mm^3)	Sand (%)	Silt (%)	Bulk density (g/cm^3)	PH	OC (%)	Total N (%)
0-30	0.68	0.45	16	18	1.04	7.83	2.13	0.13
30-60	0.44	0.35	16	18	1.18	8.13	1.2	0.1
60-90	0.40	0.31	16	14	1.22	8.01	1.22	0.07
90-115	0.27	0.12	16	14	1.26	8	1.2	0.07
115-130	0.40	0.24	44	39	1.19	7.6	0.98	0.05
130-220	0.24	0.12	17	67	1.18	7.7	0.07	0.04

Source: Ambo Agric. Res. Center
DUL, is drainage upper limit, DLL, is drainage lower limit soil, OC, Organic carbon

2.3. Methodology

The climate change projection outputs of RCP45 and RCP85 from five GCMs of CMIP5 namely: CCSM4, GFDL-ESM2M, HadGEM2-ES, MIROC5 and MPI-ESM-MR were downscaled using delta statistics method. Historical baseline daily weather data, with each day's weather variables perturbed using the changes in climate model outputs for future time periods versus those same model outputs for the historical time period was used.

2.4. Crop and Management

Based on the research recommendation for BH660 maize cultivar, we have used 4.4 plants/m^2 seeding rate between 20th of May and 10th of June as a planting window. Similarly, the nitrogen fertilizer application also based on the recommendation in such a way that a total of Fertilizer of 100kg DAP and 200kg/Ha Urea in which about 33% of the fertilizer was assumed to be applied at sowing to a depth of 0.1m and the rest 67% of fertilizer was applied at 45 day after planting. In addition, presence of 10 kg/ha of inorganic soil nitrogen, 0.1 ppm of NO3 and 0.01 ppm of NH4 and 50% of the total available water was assumed at start of sowing. The planting depth and row spacing were assumed to be 50 mm 0.75 m, respectively.

2.5. Genetic Coefficient Calculation

Many recently published journal articles [18] recommended two ways of genetic coefficient determination methods in CERES-maize model. The first one is to use the appropriate experimental data to derive the values of genetic coefficients and the second options is modifying quantitatively the benchmark of the cultivar's phenotypic characteristics using the available information. Hence we followed the first option to calibrate the maize BH660 cultivar for this climate change impact assessment.

CSM CERES in DSSAT Version 4.5 (hereafter DSSAT) [12] was calibrated using an independent maize data set of eight years of data (2002-2011). The simulation performance of the model was evaluated based on several year phenological and yield data collected at Ambo plant protection research centre. In table 2, the observed maize phenology and yield data used for model calibration and evaluation. Site specific soil, climate and management information were also used as data inputs in the model when evaluating the simulation performance of the model.

Table 2. *BH660 maize cultivar phenological data from Ambo Plant Protection Centre.*

Year	Days to maturity	Days to flowering	Grain yield (Kg/Ha)
2002	161	100	5800
2004	182	110	7500
2005	182	107	8400
2006	190	113	7700
2007	190	109	8450
2008	193	112	9000
2010	190	101	7200
2011	192	99	7240

2.6. Local Sensitivity

The local sensitivity of a model was calculated by changing ±5% of one parameters at a time (1) from the candidate input parameters (Tmax, Tmin, radiation, rainfall and CO_2 concentration) while the others remain the same and check the changes in the output due to the change in the input in the vicinity of a base value [14]. It was done for 30 years of simulated grain yield of maize.

$$\sigma_r\left(\frac{Y}{\theta}\right) = \frac{\partial Y/Y}{\partial \theta/\theta} \quad (1)$$

Where Y is simulated grain yield obtained for each level of an individual model parameter (θ) while keeping all other model parameters at their base values.

3. Results and Discussion

3.1. CERES-MAIZE Model Calibration and Sensitivity Analysis

The statistical evaluations have indicated that the model has satisfactorily simulated the corresponding observed crop data in terms of days to flowering (R^2=0.81), days to maturity (R^2=0.65) and grain yield (R^2=0.88) (see figure 4). This indicates, the model has able to simulate the yield and phenology of the cultivars adequately. Moreover, we have also checked how the model is sensitive to which environmental element due to the prevailing climate change and we have found out that that maximum temperature was the most sensitive environmental parameters from the selected factors (Figure 4D below).

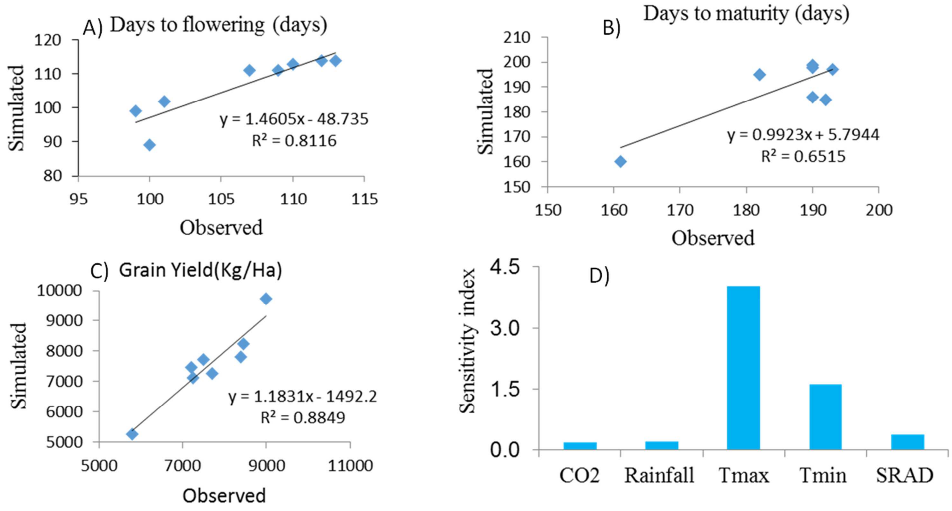

Figure 4. *The CERES-MAIZE model calibration for BH660 maize variety of: A) days to flowering (r^2=0.7), B) days to maturity (r^2=0.7), C) grain yield in Kg/Ha (r^2=0.78) and D) sensitivity of BH660 to carbon dioxide concentration, rainfall, maximum temperature, minimum temperature, and solar radiation.*

3.2. Projected Climate Change and its Impact on Maize Productivity

3.2.1. Historical and Future Climatic Trends

Analyses of annual and seasonal maximum and minimum temperatures and rainfall at Ambo station by near, mid and End- century as compared to baseline period are shown in Figure 5 and 6. All GCMs indicate rise in maximum temperature by between 0.8°C and 4.8°C and in minimum temperature 0.6 to 6.6°C. The temperature projections by the five GCMs are, however in disagreement with the projections of IPCC which show increases of about 1°C - 2°C to the 2050s and about 1.5°C -3°C for the 2080s [15] in Eastern Africa. The reasons for the disagreement may be due to the scale at which IPCC projections are made vis-a-vis the downscaling procedures used in generating the data used in these analyses. Moreover, rainfall projections for annual and the months of June, July, August and September (JJAS) rainfall show diverse results with increase as well as decrease under different GCMs. The JJAS are important in the study area because during the growing season, they span the period from juvenile stages to start of grain filling for maize. Results indicate that MIROCS and GFDL-ESM2M are the only GCMs which show that there will be a decrease in annual rainfall (see figure 5 and 6) otherwise all the GCMs showed us that there will be a higher rainfall in both annual and seasonal distribution in all RCPs (4.5 and 8.5) and all periods (Near, Mid and End – century). MPI-ESM-MR shows the highest increment in annual rainfall in RCP4.5 at the End-century.

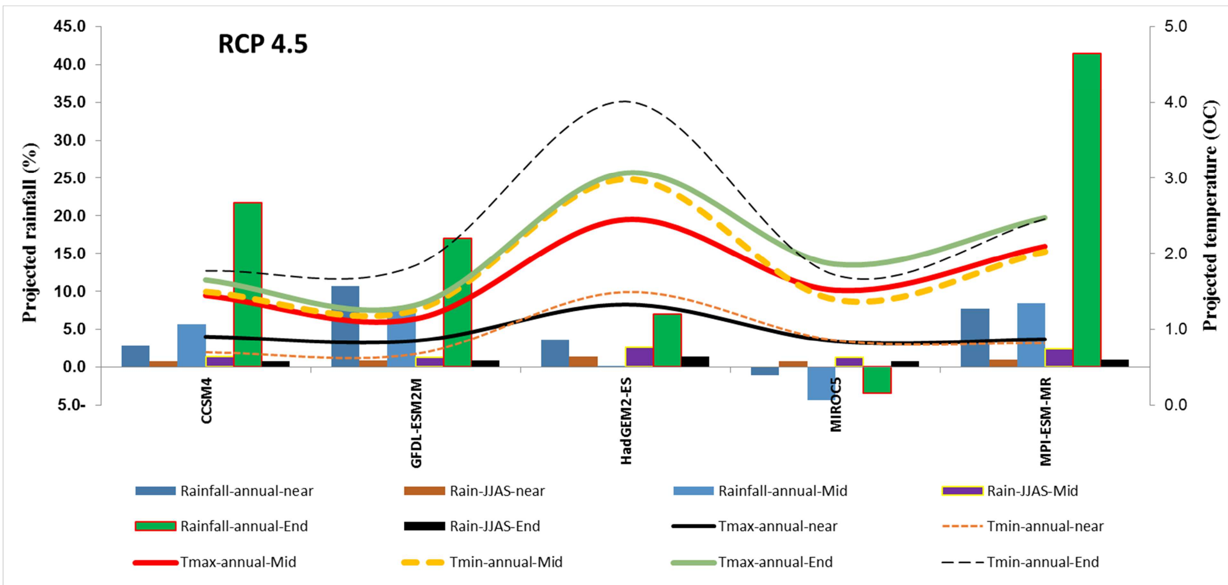

Figure 5. *Project change of rainfall and temperature under RCP-4.5 of Near-century (2011-2040), Mid-century (2041-2070) and End-century (2071-2100)*

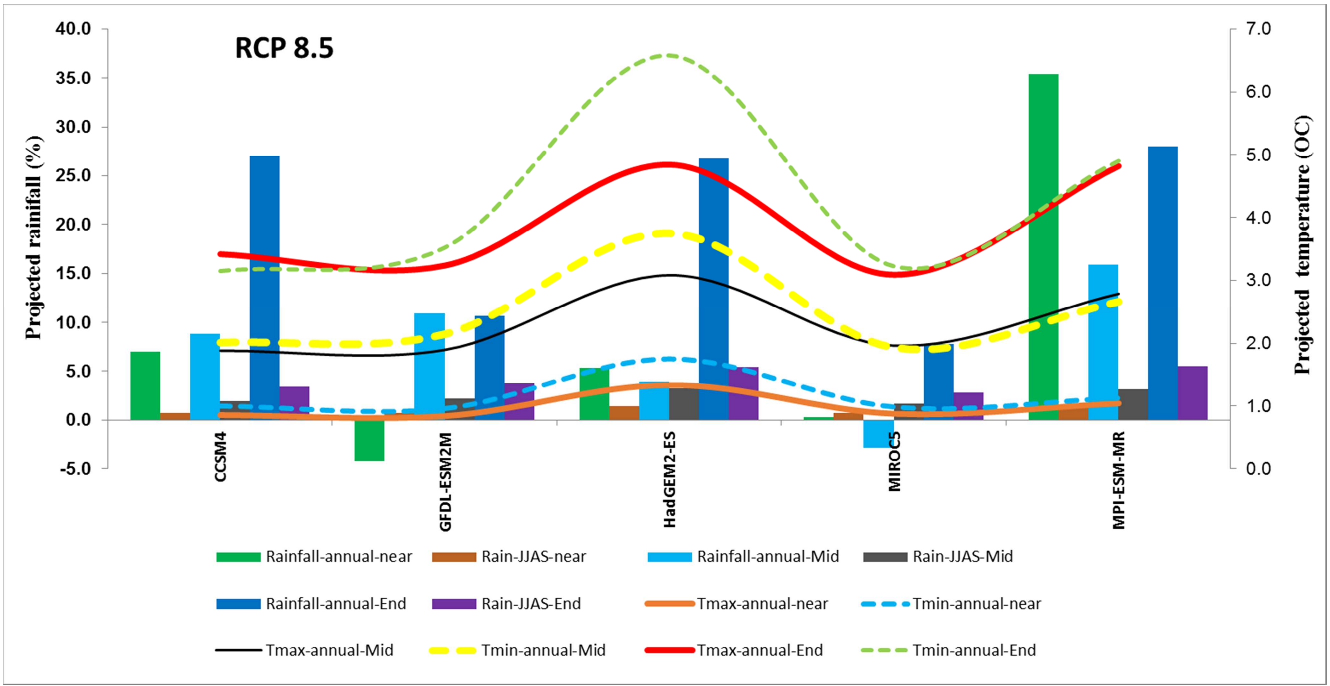

Figure 6. *Project change of rainfall and temperature under RCP-8.5 of Near-century (2011-2040), Mid-century (2041-2070) and End-century (2071-2100)*

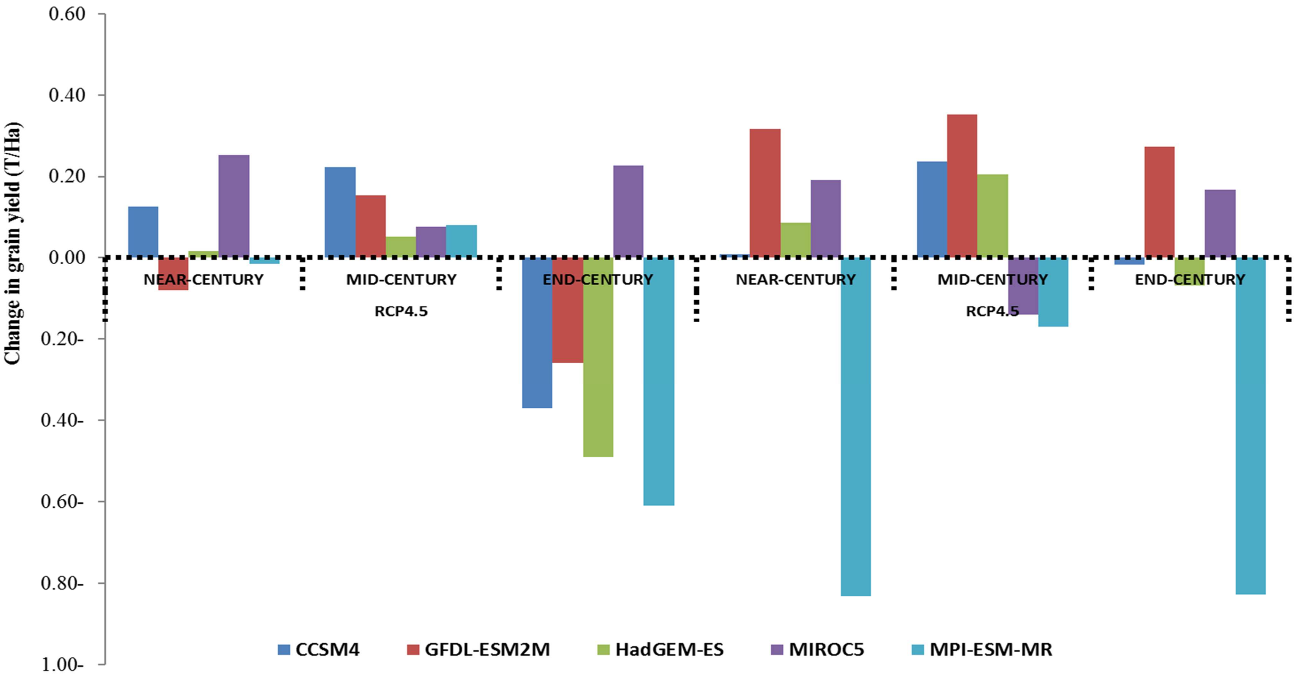

Figure 7. *Future Maize (BH660) productivity under current recommender management options and impacted climate of RCP45 and RCP85 scenarios.*

3.2.2. Projections of Maize Yields

Simulation results under different the selected five GCMs by Near, Mid and End-century under RCP 4.5 and RCP 8.5 are shown in Figure 7. The simulated grain yields under baseline (3.0 - 4.7 t/ha) give realistic estimates of the current maize grain yield obtained under the recommended management practices. The change in maize yields under both RCPs reveal that there would be a declination of maize grain yield in all projected time period in the magnitude of 0 to 5% in the future compared to baseline. Increase in rainfall amounts projected by GCMs does not match with the increase in simulated grain yields (e.g. MIROC5 under RCP 8.5 at Mid-Century) (see Figure 6) in that while decrease in annual projected rainfall but since it has got an increment on the JJAS seasonal rainfall the projected maize grain yield remains positive for the same specific period and RCP. Results from the current study are in agreement with previous studies e.g. [24] which show that crop (for instance sorghum) yields are expected to increase, decrease or remain unchanged under different GCMs, scenarios and locations hence corroborating the intrinsic uncertainty in crop yield predictions using the current methodologies.

Moreover, the analysis of impact of climate change on maize productivity shows that maize yield will increase in all models for near and mid-century in both scenarios, except for MIROC5. However, at end century particularly under RCP45 scenario all models except MIROC5 showed that yield will decline by about 0.3T/ha. As indicated in Figure 7, MPI-ESM-MR model showed exceptional decline (i.e. more than 0.8 T/ha) in maize potential yield under RCP8.5 scenarios particularly in the near and end of the century.

These studies show a wide range of possible impacts of climate change on maize in ambo, ranging from negative to positive, highlighting the need for location-specific adaptation strategies to manage risks and vulnerability associated with impacts of climate change.

3.3. Adaptation

Critical analysis of performance of different management practices that are currently used by farmers has indicated that it is not possible to adapt the future projected climate conditions. Hence it better to combine what would be the best management practices that would make better use of future climatic conditions by adopting some of the available technologies such as planning data, planting population, sawing depth and fertilizer application rate and time. For ambo Zuria wereda the best bet management practices has been mentioned in table-3.

Table 3. *Management practices that produce a better grain yield when we compares to the rest recommended practices under future climate conditions.*

Management practices	Best practices
Planting date	late planting (June 15-20)
Planting population	High population (5.3 plants/m^2)
Planting Depth	Medium (7 cm)
Fertilizer	100Kg/ha DAP and 50 Kg/ha Urea at planting and 50 kg/ha DAP and 50 Kg Urea one month later after planting

If the package of practices is adopted and strictly applied in the target District, it is possible to increase the maize yields significantly even under the worst climate change conditions. The benefits of adoption of proposed strategy as simulated by DSSAT Model results indicate potential gains in maize yield in Ambo zuria wereda under projected future climates by all five GCMs and both RCPS (figure- 8).

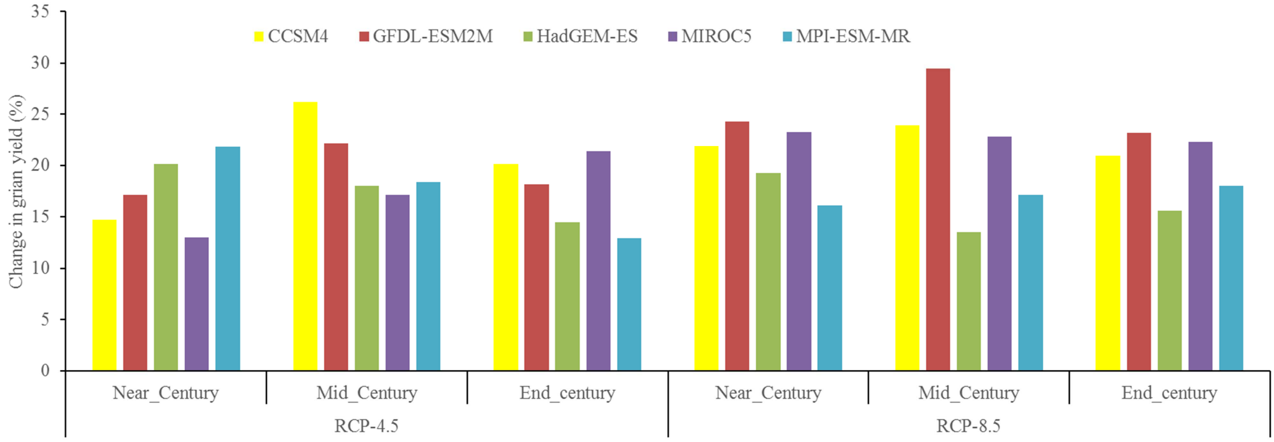

Figure 8. *Impacts of climate change under the implementation of best bet adaptation practices in place.*

4. Conclusion

The temporal change of climate change was significantly increase in both minimum and maximum temperature while rainfall don't have any distinguished signal under both scenarios (RCP 4.5 and RCP 8.5). The impacts of the projected climate on Maize (BH660) in the future climate would increase 0.3 - 0.4 T/ha however at end century it would be declined up to 0.8 T/ha and also we have found that among the considered environmental variables Maize (BH660) was more sensitive to change in maximum temperature than the other environmental factors. Even though the Median maize yield slightly decreased at the end centuries relative to the baseline, it is possible to reverse the direction of the change bring more positive yield easily by introducing some climate smart agronomic practices. Hence, in the future more research has to be carried out for assessing alternative adaptation strategies.

References

[1] Araya, A., & Stroosnijder, L. (2011). Assessing drought risk and irrigation need in northern Ethiopia. *Agricultural and Forest meteorology*, *151* (4), 425-436.

[2] Araya, A., Keesstra, S. D., & Stroosnijder, L. (2010). A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. *Agricultural and Forest Meteorology*, *150* (7), 1057-1064.

[3] Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M.,... & Yanda, P. (2007). Africa.

[4] Challinor, A., Wheeler, T., Garforth, C., Craufurd, P., & Kassam, A. (2007). Assessing the vulnerability of food crop systems in Africa to climate change. Climatic change, 83 (3), 381-399.

[5] Coe, R., & Stern, R. D. (2011). Assessing and addressing climate-induced risk in sub-Saharan rainfed agriculture: Lessons learned. Experimental Agriculture, 47 (02), 395-410.

[6] Conway, D., & Schipper, E. L. F. (2011). Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia. Global Environmental Change, 21 (1), 227-237.

[7] Cooper, D. S., Doherty, G. M., Haugen, B. R., Kloos, R. T., Lee, S. L., Mandel, S. J.,... & Sherman, S. I. (2009). Revised American Thyroid Association management guidelines for patients with thyroid nodules and differentiated thyroid cancer: the American Thyroid Association (ATA) guidelines taskforce on thyroid nodules and differentiated thyroid cancer. *Thyroid*, *19* (11), 1167-1214.

[8] Cooper, P. J. M., Dimes, J., Rao, K. P. C., Shapiro, B., Shiferaw, B., & Twomlow, S. (2008). Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change?. Agriculture, Ecosystems & Environment, 126 (1), 24-35.

[9] Demeke, A. B., Keil, A., & Zeller, M. (2011). Using panel data to estimate the effect of rainfall shocks on smallholders food security and vulnerability in rural Ethiopia. Climatic change, 108 (1-2), 185-206.

[10] Dixit, P. N., Cooper, P. J. M., Dimes, J., & Rao, K. P. (2011). Adding value to field-based agronomic research through climate risk assessment: A case study of maize production in Kitale, Kenya. Experimental Agriculture, 47 (02), 317-338.

[11] Goulder, L. H., & Pizer, W. A. (2006). The economics of climate change (No. w11923). National Bureau of Economic Research.

[12] Hoogenboom, G, Jones, J. W., Porter, C. H., Wilkens, P. W., Boote, K. J., Hunt, L. A., and Tsuji, G. Y. (Editors). 2010. Decision Support System for Agrotechnology Transfer Version 4.5. Volume 1: Overview. University of Hawaii, Honolulu, HI.

[13] Jones, P. G., & Thornton, P. K. (2009). Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. Environmental Science & Policy, 12 (4), 427-437.

[14] Jones, P. G., Thornton, P. K., & Heinke, J. (2009). Generating characteristic daily weather data using downscaled climate model data from the IPCC's Fourth Assessment.

[15] Meehl, G. A., Stocker, T. F., Collins, W. D., Friedlingstein, P., Gaye, A. T., Gregory, J. M.,... & Raper, S. C. (2007). Global climate projections. Climate change, 3495, 747-845.

[16] Parry, M. L. (Ed.). (2007). *Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC* (Vol. 4). Cambridge University Press.

[17] Pathak, T. B., Fraisse, C. W., Jones, J. W., Messina, C. D., & Hoogenboom, G. (2007). Use of global sensitivity analysis for CROPGRO cotton model development. Transactions of the ASABE, 50 (6), 2295-2302.

[18] Román-Paoli, E., Welch, S. M., & Vanderlip, R. L. (2000). Comparing genetic coefficient estimation methods using the CERES-Maize model. Agricultural Systems, 65 (1), 29-41.

[19] Rosell, S. (2011). Regional perspective on rainfall change and variability in the central highlands of Ethiopia, 1978–2007. Applied Geography, 31 (1), 329-338.

[20] Slingo, J. M., Challinor, A. J., Hoskins, B. J., & Wheeler, T. R. (2005). Introduction: food crops in a changing climate. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 360 (1463), 1983-1989.

[21] Stern, N. (2006). What is the economics of climate change?. WORLD ECONOMICS-HENLEY ON THAMES-, 7 (2), 1.

[22] Stern, N. H. (2007). The economics of climate change: the Stern review. cambridge University press.

[23] Thornton, P. K., Jones, P. G., Ericksen, P. J., & Challinor, A. J. (2011). Agriculture and food systems in sub-Saharan Africa in a 4 C+ world. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 369 (1934), 117-136.

[24] Tingem, M., Rivington, M., & Bellocchi, G. (2009). Adaptation assessments for crop production in response to climate change in Cameroon. Agronomy for sustainable development, 29 (2), 247-256.