American Journal of Applied Scientific Research
2025, Vol. 11, No. 1, pp. 48-57
https://doi.org/10.11648/j.ajasr.20251101.15

Research Article

Climate Change Adaptation Practices for Sustainable Sorghum Production in Drylands of Ethiopia

Olika Dessalegn[1,*], Eshetu Zewdu[1,2]

[1]Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia
[2]Scuola Superiore Sant' Anna, Pisa, Italy

Abstract

Climate variability and extreme events are major threats of food production that exacerbates the existing food security challenges in developing countries where agriculture is climate sensitive while adaptive capacity is low to remain productive under undoubtedly changing climate. On the other hand, the dynamically increasing human population increase the demands for more food than ever in the past while the worst climate change scenarios indicate as it would get even harder in fifty to hundred years in the future. Understanding the climate, crop and cropping system have significant importance in effective management of climate risks and designing suitable adaptation strategies for sustainable food production. Therefore, the main objective of the study was to evaluate and identify climate change adaptation practices for sorghum production over Kobo, Melkassa and Miesso as representative growing agroecologies of Ethiopia. The study was conducted using DSSAT-CSM approach depending on EMI's historical climate data and climate change data from Global Climate Models (GCMs) for mid (2040-2069) and end-term (2070-2099) periods using delta method downscaling while soil profile data was used from secondary sources. Three planting windows (16^{th} June to 30^{th} June, 1^{st} July to 15^{th} July and 16^{th} July to 30^{th} July) were used to evaluate planting date response of ESH-1, ESH-2 and Melkam Sorghum varieties to be tested in early, normal (intermidate) and late planting, respectively. The result indicated that the rainfall is expected to be increased by 3.1% at Melkassa, 4.5% at Kobo and to 7.9% at Miesso by 2050s whrereas 9.2%, 12.5% and 20.4% increment change is expected by 2080s, respectivley. The projected temperature indicated an increament of close to 2.3°C to 3.8°C. The sorghum yield response of future climate over Kobo and Miesso in both mid-term and end-term is riskier as compared to Melkassa, the one in intermediate agroecology. In the case of end-term, the yield reduction ranges from 38 percent for Melkam Varity over Kobo to 25 percent over Melkassa. On the other hand, combination of early planting and increasing the fertilizer rate by 50% would increase sorghum productivity in all cases. In general, the results indicated that climate change would aggravate the ongoing food production challenges unless appropriate adaptation plans be designed and implemented. Indeed, the findings of this study would have a potential impact for policy makers, researchers, and agricultural experts by looking for appropriate adaptation options that enable sustainable production under future climate changes scenarios.

Keywords

Adaptation, Climate Change Impact, Sorghum Production

[*]Corresponding author: oldkb2018@gmail.com (Olika Dessalegn)

Received: 19 December 2024; **Accepted:** 9 January 2025; **Published:** 22 February 2025

1. Introduction

In Ethiopia, agriculture is the key economic sector, which constitute around 50 percent of the growth domestic product (GDP) and for more than 90 percent of the national export commodity of the country [1-3]. It is also a source of livelihood for more than 85 percent of the the population. However, it is largely rainfed and manipulated by the smallholder farmers which are a highly vulnerable to climate change and variability impacts. Smallscale farmers are responsible for around 95 percent of the total area of crop production and 90 percent of the total agricultural production in Ethiopia. Basically, smallscale lead agriculture is known with low productivity, limited technology adoption capacity and high vulnerable to climate change impacts [4-6]. As a result, Ethiopia has incurred high economic costs each year for mitigating climate change and seasonal climate fluctuations induced losts [3, 7-9]. In this country, the implication of agriculture is also beyond the economic impact, it also has a significant impact for social and political stability of the country.

Crop production in Ethiopia is highly relied on seasonal rainfall characteristics that a small fluctuation in seasonal rainfall amount and distribution, onset and/or cessation of seasonal rains and dry spells characteristics that significantly determine seasonal production performance [1, 10]. This day, climate change amplifies the existing challenges of increasing variability of climate and occurrence of extreme events which intensified the existing food security challenges and poverty of Ethiopia [3, 11, 12]. Further, the poor understanding and limited access for agro-climate advisory services has also play significant contribution for the frequent crop failure and yield lose in Ethiopia [1].

According to reports [8, 13, 14], small scale farmers in dryland areas are the most vulnerable group to climate change induced and agravated consequences upon their strong livelihood reliance on rainfed based fragile farming system [15]. Furthermore, the poor research and development attention given for drylands; due to the misunderstanding of drylands contribution for economic development of the country; exacerbates the impacts and contribute for the poor attention given to the region [16]. Crop production in dryland region is subjected for multiple climatic stresses; like water stress (drought), high temperature (heat stress), strong wind and rain storms having heavy intensity [17]. High temperature and erratic nature of rainfall also causes acute water deficit in any critical crop stage; like flowering and grain filling stage; that results poor quality and loss of production [2, 18].

Therefore, the need to address such challenges would not be ignored and rather needs more attention and focus to manage the risks. In this regard, to reduce the adverse risks of climate change for crop production, the need to asses potential impacts and designing response plan; i.e. adaptation actions; are essential to sustain production and productivity. According to reports; integration of climate information and crop management practices are critical approches to conduct demand based farming practices that can offset adverse risks of climate change [19, 20]. Recently, advanced tools and methods are becoming popular and widely used to investigate climate change impacts and to evaluate adaptation strategies for sustaianable crop production. In addition, tools and approaches have potential to enable precise farming practices and climate smart agricultural developments [21]. Hence, now a days, cropping system models and climate models are widely used advanced tools to simulate cropping and climate systems processes effectively [19, 21, 22].

In this study we used CERES-sorghum of the Decision Support System for Agrotechnology Transfer (DSSATv4.7) [23] to evaluate adaptation practices for sorghum production of the future climate. Three sorghum cultivars (ESH-1, ESH-2 and *Melkam*) were selected for this study. The major objective of this study is to evaluate and identify suitable climate change adaptation practices for sorghum production that sustain production and productivity in north eastern (Kobo), Central (Melkassa) and Estern (Miesso) dryland growing areas of Ethiopia.

2. Methods

2.1. Description of the Study Sites

The study was conducted in north eastern sorghum growing regions of Ethiopia. Sirinka and Kobo from Amhara and Enderta from Tigray National Regional States were selected for this study. Three sorghum varieties are selected to investigate adaptation practices that maintain the production. Geographically, Kobo is found in between 12°09′-12°15°N and 39°38°-39.63°E. Melkassa is located between 8.391°-8.444° N and 39.315°-39.361° E. Whereas, Miesso is located between 9.088°-9.463°N and 40.404°-41.000°E. Their elevetion is 1,468 m, 1,550 m and,394 m above sea level respectively.

The study location has a semi-arid climatic condition. Based on the traditional climate classification system, the study sites lie in Kola to Woynadega agro-ecological zones. More specifically, Kobo and Miesso are categorized under Kolla; while Melkassa is categorized under Woynadega agro-ecology. Regarding rainfall regime category of the districts, Kobo and Melkassa and Miesso have all a bimodal rainfall pattern that get a small rain from mid-February to mid-May (locally known as belg) and the main rain from June to September (known as kiremt).

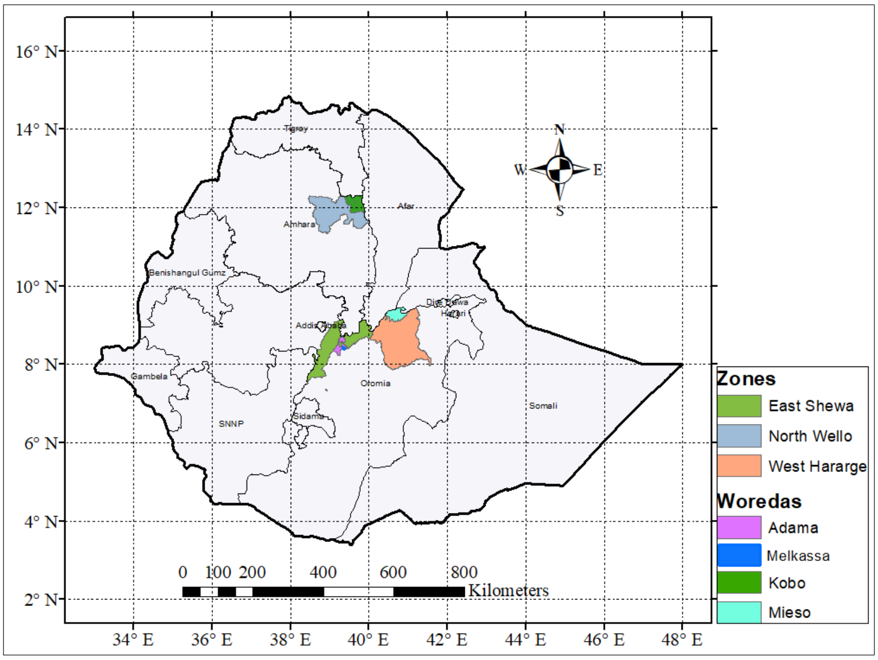

Figure 1. *Map of study sites (Kobo, Melkassa and Miesso).*

Table 1. *Historical annual and JJAS seasonal rainfall amount.*

Locations	Annual	JJAS
Kobo	679.3	405.9
Melkassa	823.7	557.5
Miesso	726.6	403.7

2.2. Data and Methods

Climate, soil physical and chemical characteristics, cultivar specific parameters and crop management data are the minimum data sets required to simulate the model [23, 24].

Soil Data: Soil data for the study districts were obtained from different sources. Soil profile data for Enderta district was obtained from [24] while the soil profile of Kobo were taken from Climate and Geospatial Research department of Ethiopian Institute of Agricultural Research (EIAR). Some important soil parameters required to run the model like Bulk density (BD), drained upper limit (DUL), drained lower limit (DLL), saturation (SAT), root growth factor (RGF) and saturated hydraulic conductivity (SKs) not measured and presented were estimated from soil texture data using Decision Support System for Agro-technology Transfer (DSSAT4.7) SBUILD software package. The soil data was taken from [12].

Climate Data: Daily rainfall, maximum and minimum air temperatures data for Sirinka and Kobo districts were obtained from Ethiopian Institute of Agricultural Research (EIAR). Whereas, daily data for Enderta which ranges from 1980 to 2017 used for this study site, was taken from Ethiopian Meteorological Institute (EMI). Solar radiation data was estimated from air temperature and latitude data using DSSAT4.6 weather module. The observed data were subjected for quality visualization and inspections using RClimDex1.0 to detect potential errors that cause changes in the seasonal cycle or variance of the data [25].

Site specific climate change scenario data for the study sites were downscaled using Agricultural Model Inter-comparison and Improvement Project (AgMIP) climate scenario generation scripts for 20-global climate models (20-GCM's) from the ready-made data sets for east Africa region [26]. IPCC fifth assessment report (AR5) of Representative Concentration Pathway's (RCP's) assumption were used to downscale site specific climate change scenario data for the study districts. The scenarios were developed for the two RCP's (RCP4.5 and RCP8.5) using a delta based downscaling approach (Reference). For model biases, the delta method adopts that the future mean and variability of climate will be the same as those in present day simulations [27]. The model was used to downscale both temperature (minimum and maximum) and rainfall data of future climate for each study locations. Once downscaled, the data was subjected for further analysis and comparison with the base period of each respective sites. In this case, the absolute differences between means in temperature and percentage change in precipitation were used to describe future climate change of the locations with respect to the base period.

Crop and Management Data: Commonly grown varieties of sorghum (ESH-1, ESH-2 and Melkam) were used as a testing crops. ESH-1, ESH02 and Melkam sorghum varieties are released for dry lowland areas where frequent drought and water deficit are common. They are categorized early to medium maturity groups.

Crop Model

For this study, Decision Support System for Agrotechnology Transfer (DSSAT4.7) is used to evaluate the possible climate change adaptation practices. DSSAT is a software system which contains a combination of crop growth models and database management tools that have been used to evaluate models, estimate crop specific parameters (genetic coefficients), and to evaluate alternative management practices [28]. DSSAT simulates growth and development of crops in response to weather, soil and crop management practices [29]. The sorghum cultivars' genetic coefficients were obtained from [12, 30].

Table 2. *Estimated Genetic Coefficients values for Sorghum cultivars (ESH-1, ESH-2 and Melkam) at Kobo, Melkassa and Miesso sites in the drylands of Ethiopia [12].*

Genetic parameters	Description	Estimated coef.	
		Teshale	Melkam
P1	Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8°C) during which the plant is not responsive to changes in photoperiod	250.1	311.7
P2O	Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate. At values higher than P20, the rate of development is reduced	12.46	12.46
P2R	Extent to which phasic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P20.	101.7	154.4
P5	Thermal time (degree days above a base temperature of 8°C) from beginning of grain filling (3 - 4 days after flowering) to physiological maturity	492.8	480.8
G1	Scaler for relative leaf size	5.512	6.4
G2	Scaler for partitioning of assimilates to the panicle (head).	5.255	5.0

Climate Change Adaptation

Crop production is affected biophysically by the changing climate such as rising temperature, changing rainfall regimes and the increasing level of atmospharic carbon dioxide [31]. In Ethiopia crop production is strongly correlated with climate which makes crop production highly sensetive for climate change and variability. Therefore, the need of Agricultural adaptation to climate change at the farm level depends on the technological potential such as different varieties of crops and irrigation management, soil and water condition, and biological response of the crops [31]. In this study, planting window and fertilizer application rate were taken and evaluated as adaptation packages.

Planting date: Three planting windows from 16th to 30th June, 1st to 15th Jul and 16th to 30th July were considered to evaluate the response of sorghum yield for projected climate change scenarios for Mid and End periods under RCP4.5 and RCP8.5.

Fertilizer application rate: Different rates of fertilizer application were simulated with projected future climate change scenarios to investigate the performance of sorghum production.

Table 3. *Fertilization rate (nitrogen) treatments for future sorghum production.*

Nutrient Type	Treatment-1		Treatment-2		Treatment-3	
	DAP (150 kg/ha)	Urea (100 kg/ha)	DAP (100 kg/ha)	Urea (75 kg/ha)	DAP (75 kg/ha)	Urea (50 kg/ha)
N-kg/ha	27	46	18	35	14	23
P-kg/ha	69		46		35	

Finally, yield of sorghum cultivars were simulated using both the base and the projected periods. Finally, the performance of both crops with the prescribed changes was compared with the historic yield as follows.

$$\Delta Yield = \frac{Y_{Predicted-}\ Y_{base}}{Y_{base}}$$

Where $Y_{predicted}$ is predicted yield (kg ha^{-1}), Y_{base} is yield of the base period (kg ha^{-1}) and Δ_{yield} is the yield difference (%).

3. Result and Discussion

3.1. Projected Rainfall and Temperature Changes

Projected Rainfall

The result of projected rainfall indicated an increase of annual rainfall by 2050s and 2080s in the study districts. It is expected to be increased by 3.1% at Melkassa, 4.5% at Kobo and to 7.9% at Miesso by 2050s whrereas 9.2%, 12.5% and 20.4% increment change is expected by 2080s, respectivley. Variation of projected annual rainfall is observed across location, GCMs, and time periods. The result further indicated that, June to September (Kiremt) rainfall is projected to be increase as of the annual rainfall. Conditioned on the type of emission scenario and study locations, Kiremt rainfall is expected to increase by 2.1% at Melkassa, 1.3% at Miesso and 4.6% at Kobo by 2050s while the increment ranges 5.8% at Melkassa, 6.0% at Miesso and 9.4% at Kobo by 2080s. In general, the projected rainfall is varied across locations, the GCMs used and growing season. According to [32], the warming and increasing convection of the southern Indian Ocean are the basic drivers for the spatial variability of African climate. In addition, Inter-Tropical Convergence Zone (ITCZ), monsoons, and El Niño-Southern Oscillation of the Pacific Ocean are important derives for Africa's climate variation [33]. In general, both June to September and annual rainfall total is expected to increase at mid and end periods for north eastern, Central and Eastern dryland regions of Ethiopia.

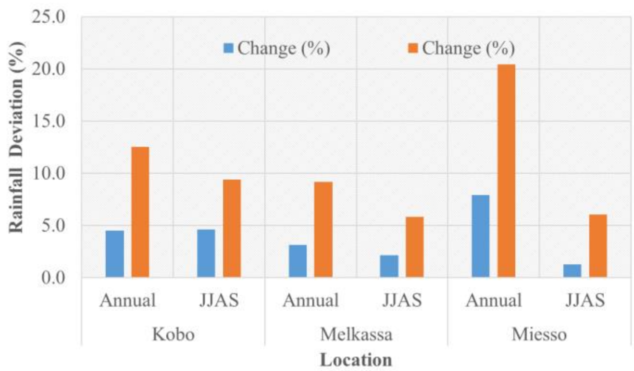

Figure 2. Deviation of rainfall by locatoin by 2050s and 2080s.

Projected Temperature

Projected temperature indicated that the study districts will experience warmer temperature than these days by 2050s and 2080s. On the average, annual maximum temperature is expected to be increased by 2.3°C and 3.4°C by 2050s and 2080s respectively, while it is expected to be increase by 2.6°C and 3.8°C during JJAS by 2050s and 2080s at Miesso. The annual maximum temperature is expected to be increased by 2.3°C and 3.3°C by 2050s and 2080s, while it is expected to be increase by 2.3°C and 3.5°C during JJAS by 2050s and 2080s at Kobo. The annual maximum temperature is expected to be increased by 2.3°C and 3.5°C by 2050s and 2080s, while it is expected to be increased by 2.5°C and 3.9°C during JJAS by 2050s and 2080s at Melkassa. Likewise, the projected mean annual minimum temperature at Miesso, Kobo and Melkassa reveals increments by 2.4°C, 2.6°C and 2.4°C, and 3.7°C, 4.0°C and 3.8°C by 2050s and 2080s, respectively. The projected mean minimum temperature change of JJAS by 2050s and 2080 respectively, were found to be 2.4°C, 2.5°C, 2.4°C, and 3.6°C, 3.8°C, 3.7°C at Miesso, Kobo and Melkassa in respective order.

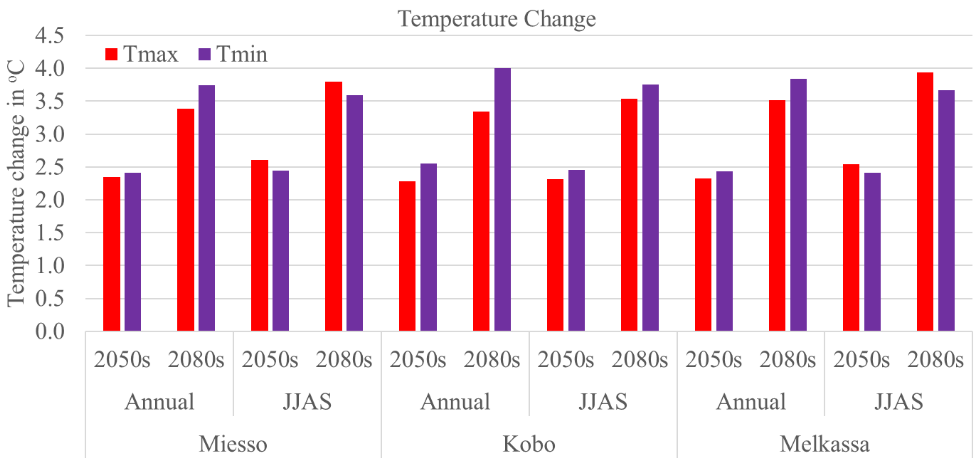

Figure 3. Projected change in temperature at Miesso, Kobo and Melkassa districts by 2050s and 2080s.

3.2. Impacts of Climate Change on Sorghum Production

Sorghum yield response for projected future climate is depicted in Figure 2. The result indicated that sorghum production in North East, Central and Eastern dryland of Ethiopia will be negatively affected by the future climate. Accordingly, sorghum yield is projected to be declined in the future. By 2080s, climate change is seriously affected sorghum production. Most studies clearly showed that elevated CO_2 least benefit sorghum relative to wheat consistent to this study [12].

3.3. Evaluation of Adaptation Practices for Sorghum Production

To reduce climate change uncertainties, following farming practices that better cope with the existing climate is most important and timely action for improving and sustaining food production [34, 35]. Therefore, identifying best practices that suit with the changing climate is urgently needed for rainfed agriculure like that of ours. In this study, the performance of sorghum production for different *planting date and fertilizer applicatio*n was evaluated under the projected future climate scenario using CERES-Sorghum cropping system models (CSMs).

In rainfed crop production system, the key question is how we can achieve sustainable yield increase that is supposed to feed the dynamically incresasing human populaton under the changing and variable climate. Agrnomic management plays a significant role to determine vegetative, reproductive development and final grain filling stage [36]. In addition, to reduce the adverse impacts of climate change, identification and evaluation of appropriate adaptation practices are paramount actions taken for sustainable production. The planting window and fertilizer application rate were evaluated and presented below as part of adaptation practice.

Planting Date

Planting date adaptation simulated in this study presented response of sorghum yield to different planting windows as part of averting climate change negative impact. The result revealed that, regardless of the emission scenarios and the period considered, early planting (16-30 June) would give a better yield for all sorghum varieties at Kobo, Melkassa and Miesso. However, delaying the planting dates beyond the normal would result in reduction of yield for all of the varieties at Kobo, Miesso and Miesso.

Fertilizer Application Rate

The response of yield for nitrogen fertilizer under the future climate showed an increase in yield for sorghum and wheat. Comparison of future and current yield responses of the three sorghum varieties for different fertilization rates under projected future climate is portrayed in Figure 5. The result indicated that increasing of N fertilization rate would result in increased yield of all sorghum cultivars by 2050s and 2080s at Kobo, Melkassa and Miesso.

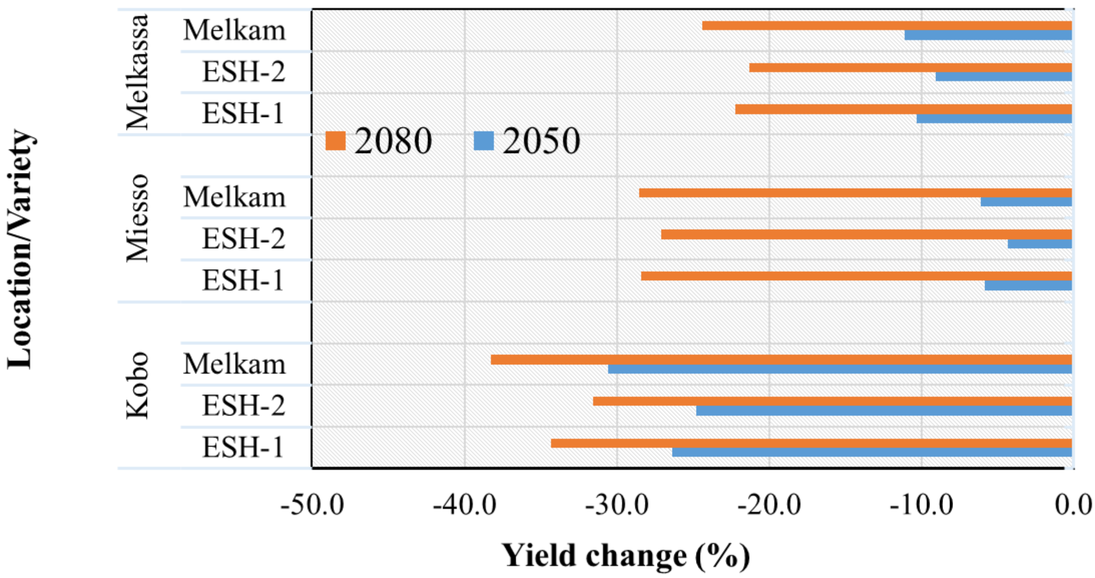

Figure 4. *Yield response of sorghum for different fertilizer application rates by 2050s and 2080s under different emission scenarios at Kobo, Melkassa and Miesso.*

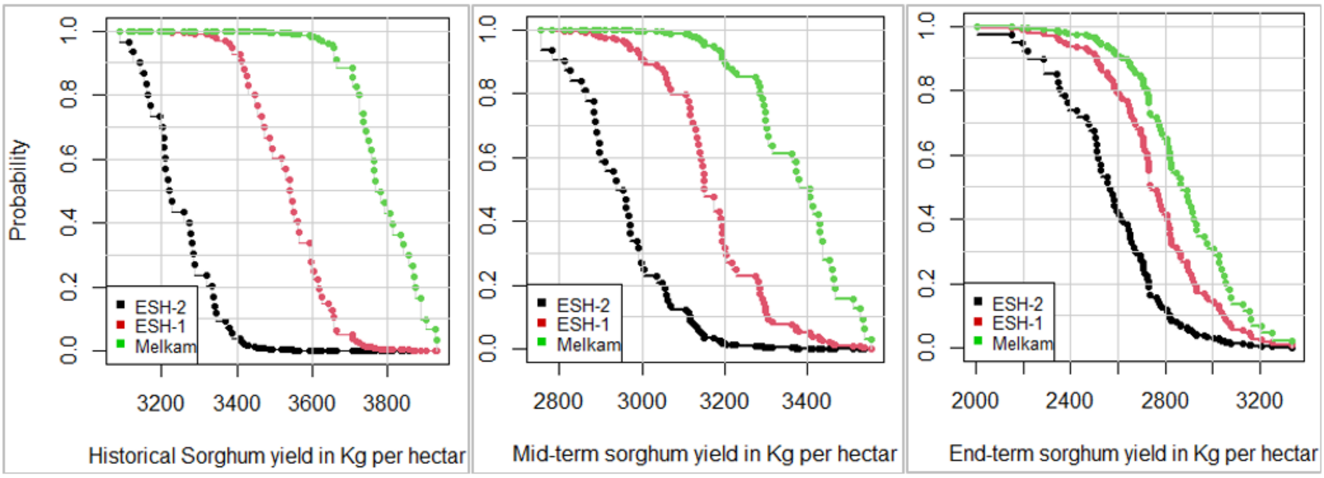

Figure 5. *Sorghum production baseline, mid-term and end-term emission scenarios.*

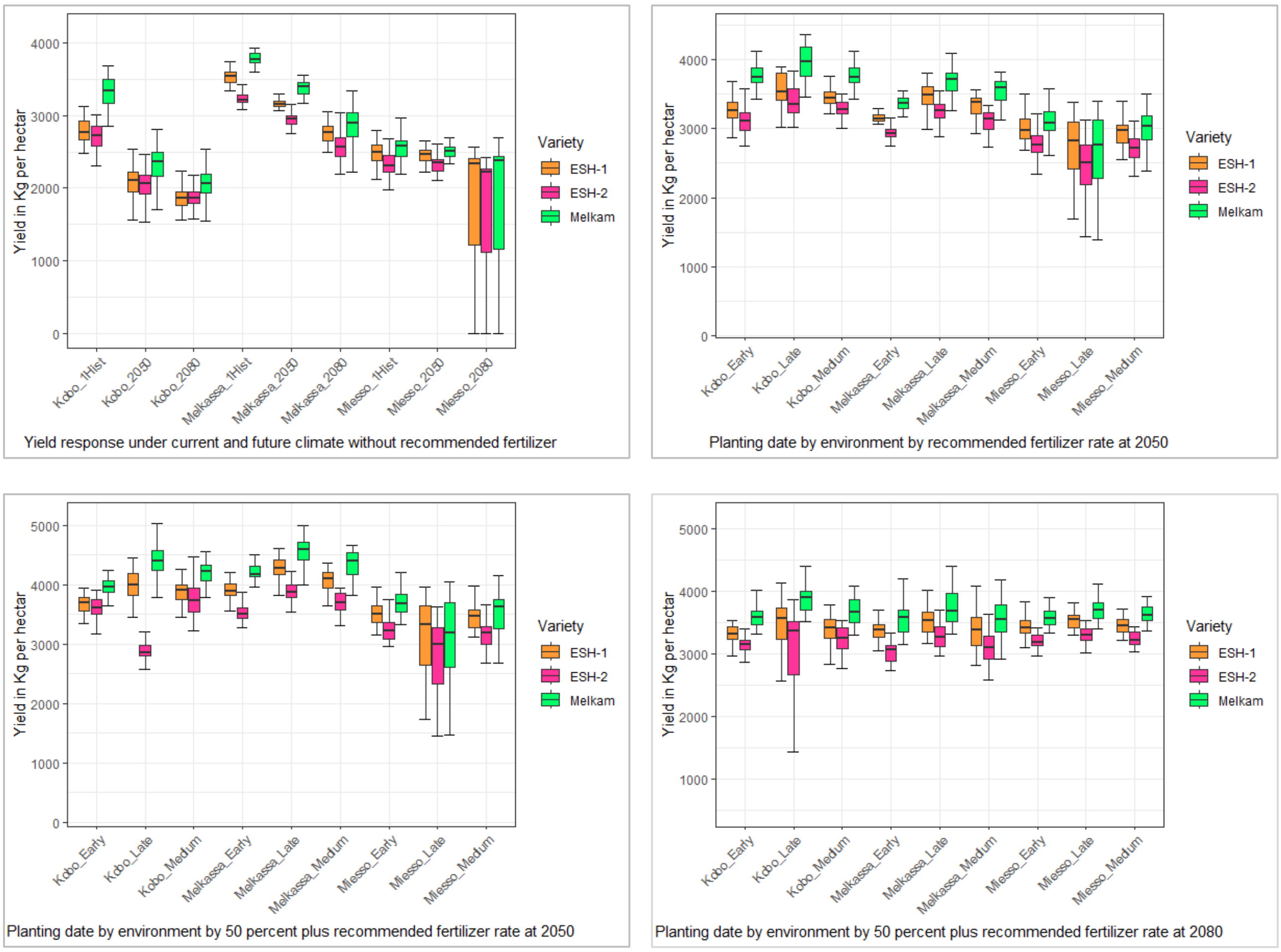

Figure 6. *Yield response of sorghum varieties under current and future climate scenarios without recommended amount of fertilizer, planting date adjusted by recommended fertilzer at 2050, improving the recommended fertilizer by 50 percent at 2050s and at 2080s, respectively.*

4. Conclusion

Recently, due to the growing concentration of greenhouse gases (GHGs) in the atmosphere, the issue of climate change has moved to the forefront of the global scientific agenda. Ethiopia is arguably the most exposed country for climate change impact due to the high reliance on rainfed system. In view of this, the study was conducted to evaluate and identify climate change adaptation practices that would increase sorghum productivity under the future climate. The study was conducted in three districts (Kobo, Melkassa and Miesso) representing lowland and mid-highland agro-ecologies. Cropping system model, DSSATv4.8, was used to investigate potential adaptation practices for future sorghum production. Crop management practices; planting date and fertilizer application were evaluated under the projected climate scenarios.

According to the result, the study districts will experienced warmer temperature in the future than today. The projected mean annual minimum temperature at Kobo, Melkassa and Miesso reveals increments by 2.6°C, 2.4°C and 2.4°C, and 4.0°C, 3.8°C and 3.7°C by 2050s and 2080s, respectively. The projected mean minimum temperature change of JJAS by 2050s and 2080 respectively, were investigated to be 2.4°C, 2.5°C, 2.4°C, and 3.6°C, 3.8°C, 3.7°C at Miesso, Kobo and Melkassa in respective order. Moreover, the rainfall is expected to be increased by 4.5% at Kobo, 3.1% at Melkassa, and to 7.9% at Miesso by 2050s whrereas 12.5%, 9.2% and 20.4% increment is expected by 2080s, respectivley. The result further indicated that, June to September (Kiremt) rainfall is projected to be increase as of the annual rainfall. Conditioned on the type of emission scenario and study locations, Kiremt rainfall is expected to increase by 2.1% at Melkassa, 1.3% at Miesso and 4.6% at Kobo by 2050s while the increment ranges 5.8% at Melkassa, 6.0% at Miesso and 9.4% at Kobo by 2080s.

Moreover, the results indicated that yield response for the future climate is varied among the locations and varieties. Future production of sorghum varieties was investigated to be improved by combined adjustment of planting windows and fifty percent additional application of fertilizer application in all locations at end-term (2080) while the productivity decline at Miesso regardless of 50 percent additional fertilizer application in late planting window. More generally, late planting windows decrease the productivity compared to early and midium planting windows in all location case studies.

5. Recommendation

Based on the findings of this study, we are recommended that:

1) Assessment of climate change impacts on crop production as well as ecosystem service should consider multiple climate model (GCMs) to enhance predictability.
2) Future policy options need to fine-tune climate change adaptation technologies based on agro-ecological settings.
3) Agricultural research and development support systems need to focus on developing/adapting crop types and/or varieties resistant to heat and drought stress with appropriate level of extension and promotion services.
4) Focus need to set on integrated farm level crop management practices to increase the yield of wheat and sorghum under climate change conditions.

Cropping system model integrates the biophysical, economic, social and institutional aspects of a system under study could be helpful to assess the impact of climate change on crop production and explore suitable adaptation practices for further studies.

Abbreviations

AgMIP	Agricultural Model Intercomparison and Improvement Project
AR5	Fifth Assessement Report
BD	Bulk Density
CERES	Crop Environment Resource Synthesis
CSM	Crop System Model
DLL	Drained Lower Limit
DSSAT	Decision Support System Agrotechnology Transfer
DUL	Drained Upper Limit
EIAR	Ethiopian Institute of Agricultural Research
EMI	Ethiopian Meteorological Institute
GCM	Global Climate Model
GDP	Growth Domestic Product
GHGs	Greenhouse Gases
IPCC	Intergovernmental Panel for Climate Change
ITCZ	Inter-Tropical Convergence Zone
JJAS	June, July, Augest and September
RCP	Representative Concentration Pathway
RGF	Root Growth Factor
SAT	Saturation
SBUILD	Soil Data Uitility
SKs	Saturated Hydroulic Condactivity

Acknowledgments

We are grateful for Ethiopian Institute of Agricultural Research for its financial and technical support to conduct this work.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] T. W. Bank, “Agro-climate tools for a new climate-smart agriculture,” 2011.

[2] FAO, “IMPACT OF NATURAL HAZARDS AND DISASTERS ON AGRICULTURE THE A CALL FOR ACTION,” no. May, 2015.

[3] CSA, “Agricultural Sample Survey Report on Area and Production (Private Peasant Holdings Meher Season),” *Cent. Stat. Agency Ethiop. Bull.*, vol. 1, no. 586, pp. 1-54, 2018, [Online]. Available: https://www.oecd.org/dac/accountable-effective-institutions/Governance Notebook 2.6 Smoke.pdf

[4] J. W. J. and G. H. K. J. Boote, "Crop simulation models as tools for agro-advisories for weather and disease effects on production." 2008.

[5] T. B. Urgessa, "Review of challenges and prospects of agricultural production and productivity in Ethiopia.," *J. Nat. Sci. Res.*, vol. 4, no. 18, pp. 70-77, 2014, [Online]. Available: http://www.iiste.org/Journals/index.php/JNSR/article/view/15857/16354

[6] G. E. O. Ogutu, W. H. P. Franssen, I. Supit, P. Omondi, and R. W. A. Hutjes, "Probabilistic maize yield prediction over East Africa using dynamic ensemble seasonal climate forecasts," *Agric. For. Meteorol.*, vol. 250-251, no. December 2017, pp. 243-261, 2018, https://doi.org/10.1016/j.agrformet.2017.12.256

[7] S. Program, E. Ii, A. S. Taffesse, P. A. Dorosh, S. A. Gemessa, and S. Asrat, "Crop Production in Ethiopia: Regional Patterns and Trends," *Food Agric. Ethiop. Prog. Policy Challenges*, no. Essp Ii, pp. 53-83, 2011, [Online]. Available: http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/127350

[8] MoANR, "Agricultural Extension Strategy of Ethiopia," p. 56, 2017.

[9] FAO, *Social protection and agriculture: Breaking the cycle of rural poverty*. 2015.

[10] E. Bryan, T. T. Deressa, G. A. Gbetibouo, and C. Ringler, "Adaptation to climate change in Ethiopia and South Africa : options and constraints," vol. 12, pp. 413-426, 2009, https://doi.org/10.1016/j.envsci.2008.11.002

[11] D. Korecha and A. G. Barnston, "Predictability of June-September rainfall in Ethiopia," *Mon. Weather Rev.*, vol. 135, no. 2, pp. 628-650, Feb. 2007, https://doi.org/10.1175/MWR3304.1

[12] Z. Eshetu, H. Gebre, and N. Lisanework, "Impacts of climate change on sorghum production in North Eastern Ethiopia," *African J. Environ. Sci. Technol.*, vol. 14, no. 2, pp. 49-63, 2020, https://doi.org/10.5897/ajest2019.2803

[13] F. Ward, "National Meteorological Agency Agrometeorological," vol. 16, no. 27, pp. 1-21, 2006.

[14] M. Winthrop, T. Kajumba, and S. McIvor, "Ethiopia Country Climate Risk Assessment Report," *Irish Aid*, no. February, p. 44, 2018, [Online]. Available: https://www.climatelearningplatform.org/

[15] M. M. Kidane Georgis, Alemneh Dejene, *ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT WORKING PAPER Inventory of Adaptation Practices and Technologies of Ethiopia Agricultural based Livelihood Systems in Drylands in the Context*. 2010.

[16] A. T. and G. A. Kidane Giorgis, "AGRICULTURAL DEVELOPMENT IN DROUGHT-PRONE AREAS OF ETHIOPIA: Interventions, Challenges and Good Practice," 2018. [Online]. Available: www.agri-learning-ethiopia.org

[17] FAO, *Agricultural based Livelihood Systems in Drylands in the Context of Climate Change*, vol. 45, no. 2. 2010.

[18] P. Singh *et al.*, "Quantifying potential benefits of drought and heat tolerance in rainy season sorghum for adapting to climate change," *Agric. For. Meteorol.*, vol. 185, pp. 37-48, 2014, https://doi.org/10.1016/j.agrformet.2013.10.012

[19] M. Bernardi, "Strengthening Operational Agrometeorological Services at the National Level - Proceedings of the Inter-regional Workshop MArch 22-26, 2004, Manila, Philippines," no. January 2004, p. 238, 2006.

[20] S. Savary, A. Ficke, J. N. Aubertot, and C. Hollier, "Crop losses due to diseases and their implications for global food production losses and food security," *Food Secur.*, vol. 4, no. 4, pp. 519-537, 2012, https://doi.org/10.1007/s12571-012-0200-5

[21] A. Kassam *et al.*, *Natural Resource Assessment for Crop and Land Suitability: An application for selected bioenergy crops in Southern Africa region Plant Production and Protection division Food and agriculture organization oF the united nations Rome, 2012*, vol. 14. 2012.

[22] J. W. Jones, J. He, K. J. Boote, P. Wilkens, C. H. Porter, and Z. Hu, "Estimating DSSAT cropping system cultivar-specific parameters using bayesian techniques," *Methods Introd. Syst. Model. into Agric. Res.*, vol. 2, no. January, pp. 365-393, 2015, https://doi.org/10.2134/advagricsystmodel2.c13

[23] J. W. Jones *et al.*, *The DSSAT cropping system model*, vol. 18. 2003.

[24] A. Yakoub, J. Lloveras, A. Biau, J. L. Lindquist, and J. I. Lizaso, "Testing and improving the maize models in DSSAT: Development, growth, yield, and N uptake," *F. Crop. Res.*, vol. 212, no. July, pp. 95-106, 2017, https://doi.org/10.1016/j.fcr.2017.07.002

[25] G. Aspects, *Manual on the Global Observing System (Annex V to the WMO Technical Regulations)*, vol. I, no. 544. 2003.

[26] A. C. Ruane, R. Goldberg, and J. Chryssanthacopoulos, "Climate forcing datasets for agricultural modeling: Merged products for gap-filling and historical climate series estimation," *Agric. For. Meteorol.*, vol. 200, no. 2015, pp. 233-248, 2015, https://doi.org/10.1016/j.agrformet.2014.09.016

[27] J. Ramirez-villegas, "CGIAR Climate Change Adaptation work as it relates to GYGA".

[28] W. Wu, J. long Chen, H. bin Liu, A. Garcia y Garcia, and G. Hoogenboom, "Parameterizing soil and weather inputs for crop simulation models using the VEMAP database," *Agric. Ecosyst. Environ.*, vol. 135, no. 1-2, pp. 111-118, 2010, https://doi.org/10.1016/j.agee.2009.08.016

[29] M. Jones and A. Singels, "DSSAT v4.5 - Canegro Sugarcane Plant Module User Documentation," no. December, pp. 1-57, 2008.

[30] M. B. Richman, L. M. Leslie, and Z. T. Segele, "Classifying Drought in Ethiopia Using Machine Learning," in *Procedia Computer Science*, Elsevier B. V., 2016, pp. 229-236. https://doi.org/10.1016/j.procs.2016.09.319

[31] T. Younos and C. A. Grady, *Climate Change and Water Resources. The Handbook of Environmental Chemistry*, vol. 25. 2013.

[32] C. Funk *et al.*, "Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 105, no. 32, pp. 11081-11086, 2008, https://doi.org/10.1073/pnas.0708196105

[33] A. Bukantis and E. Rimkus, "Climate variability and change in Lithuania," *Acta Zool. Litu.*, vol. 15, no. 2, pp. 100-104, 2005, https://doi.org/10.1080/13921657.2005.10512382

[34] S. Syamsuri, S. Sulistyowati, and I. Wibawa, "Disparitas Pertimbangan Hakim Dalam Penetapan Dispensasi Kawin Dalam Prespektif Pencegahan Perkawinan Usia Dini Di Pengadilan Agama Kudus," *J. Suara Keadilan*, vol. 20, no. 1, pp. 59-64, 2019, https://doi.org/10.24176/sk.v20i1.5558

[35] M. Yang *et al.*, "The role of climate in the trend and variability of Ethiopia's cereal crop yields," *Sci. Total Environ.*, vol. 723, Jun. 2020, https://doi.org/10.1016/j.scitotenv.2020.137893

[36] P. Singh, K. J. Boote, U. Kumar, K. Srinivas, S. N. Nigam, and J. W. Jones, "Evaluation of Genetic Traits for Improving Productivity and Adaptation of Groundnut to Climate Change in India," *J. Agron. Crop Sci.*, vol. 198, no. 5, pp. 399-413, 2012, https://doi.org/10.1111/j.1439-037X.2012.00522.x