FRR Vol 7(58):754-766

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

Eshetu Zewdu[1*] and Olika Desalegn[1]

[1]Ethiopian Institute of Agricultural Research
P.O.Box 2003, Addis Ababa, Ethiopia
**Corresponding author Eshetu Zewdu*
Email: eshe.lucky@gmail.com;

Citation: Zewdu E and Desalegn O. (2023) Climate change adaptation practices for sustainable sorghum and wheat production in drylands of Ethiopia. FARA Research Report *Vol 7(58):754-766*. https://doi.org/10.59101/frr072358

Abstract:

This day, climate variability and climate extreme events are increasingly growing and poses existential impact on practical agriculture. In developing and least developed countries, agriculture is strongly rainfed-and climate sensitive. Due to this, climate variability and shock has posed a serious impact on crop production which needs a close attention to offset the adverse impacts. In addition, the poor experience of using climate information for farm decision-making exacerbates the impacts also. Therefore, understanding the climate, crop and cropping systems are significantly important to manage climate risks and design suitable adaptation strategies. Today, advanced tools and methods such as are widely used to precise farming practices. **Decision Support System for Agro-Technology Transfer (DSSAT);** is the one used to estimate farming practices as a function of weather, soil and different management practices. Therefore, the main goal of this study was to evaluate and identify climate change adaptation practices for sorghum and wheat production for semi-arid growing areas of Ethiopia. Accordingly, current climate data for the study regions were obtained from National Meteorology Agency of Ethiopia and climate change scenario data for mid (2040–2069) and end (2070-2099) periods were obtained from Global Climate Models using delta method downscaling approach. Accordingly, the results indicated that sorghum and wheat yield response for future climate is varied spatially and temporally. Production in lowland areas is a bit risky compared to midland and highland areas according the result. Sorghum is expected to be negatively affected relative to wheat, that would get a slight positive advantage of the future climate. On the other hand, mid-June planting and increasing the rate of fertilizer would increase sorghum productivity. In general, the results indicated that climate change would aggravate the ongoing food production challenges unless appropriate adaptation plans be designed and actions taken. Indeed, the findings of this study would have a potential impact for policy makers, researchers, and agricultural experts regarding future sorghum and Wheat production that enable them to be aware of the adverse impacts and the possible solutions.

Keywords: Adaptation, Climate change, Impact, Sensitivity, Sorghum, Wheat

1. Introduction

In Ethiopia, agriculture is the key economic sector, which constitute for around 50 percent of the growth domestic product (GDP) and for more than 90 percent of the national export commodity suply of the country *(World Bank, 2011; FAO, 2016;* CSA, 2018). It is also a source of livelihood for more than 85 percent of the nations. However, this huge and critical economic sector is largely rainfed and manipulated by the smallholder farmers which are a highly vulnerable community of 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, this smallscale lead agriculture is well understood by its low productivity, limited technology adoption, poor capablity and high vulnerability for climate change impacts (Boote et al., 2008; Bekabil, 2014; FAO, 2019). As a result, Ethiopia has incurred high economic costs annually due to such limiting factors and climate change manipulated seasonal climate fluctuations (IFPRI, 2010; MoA, 2011; FAO, 2015; CSA, 2018). 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 (CSA, 2018).

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 (World Bank, 2011; Bryan et al. 2009). This day, climate change amplifies the existing challenges of through increasing variability of climate and occurrence of extreme events which intensified the existing food security challenges and poverty of Ethiopia (NMA, 2007; CSA, 2018; Zewdu et al., 2020). 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 (World Bank, 2011).

According to reports (NMA, 2007; MoA, 2011; Irish AID, 2018), small scale farmers in dryland areas are the most vulnerable group for climate change induced and agravated consequences upon their strong livelihood reliance on rainfed based fragile farming system (Georgis et al., 2009). 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 (Giorgis; et al., 2018). 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 (Georgis et al., 2009). High temperature and erratic nature of rainfall in the region also causes acute water deficit in any critical crop stage; like flowering and grain filling stage; that results poor quality and loss of production (Singh et al., 2014; FAO, 2015).

Therefore, the need to address such challenges would not be ignored and rather needs more attention and focus to manage the rsiks. 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 (WMO, 2004; FAO, 2012). Since a recent, 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 capability to precise farming practices and climate smart agricultural developments (FAO, 2012). Now a days, cropping system and climate models are widely used advanced tools to simulate cropping and climate systems processes (WMO, 2004; Jones et al., 2010;FAO, 2012).).

In this study we used cropping system models; CERES-sorghum and CERES-wheat of the Decision Support System for Agrotechnology Transfer (DSSATv4.7) (J. W. Jones et al., 2003); to evaluate adaptation practices for sorghum and wheat production of the future climate. With this, two sorghum cultivars (*Melkam and Teshale*) and Mekele-1 wheat cultivar were selected for this study. The major objective of this study is to evaluate and identify suitable climate change adaptation practices for sorghum and wheat production that sustain production and productivity in north eastern dryland growing areas of Ethiopia.

2. Materials and Methods

2.1. Description of the Study Sites

The study was conducted in north eastern sorghum and wheat growing regions of Ethiopia. Sirinka and Kobo from Amhara and Enderta from Tigray National Regional States were selected for this study. Two crops, sorghum and wheat, were selected to investigate adaptation practices for future sorghum and wheat production. Geographically, Sirinka is situated between 11o41′ and 11°49′N latitude; and 39°07′ and 39°42′E longitude with an elevation that ranges between of 1749 - 2033 m.a.s.l. Kobo is found in between 12°09′N and 12°15°N latitude and 39°38°E and 39.63°E longitude with elevation of 1468 m.a.s.l. And Enderta is located in between 13.22°N and 13.35°N latitude and 39.29°E to 39.36°E longitude with an elevation of 1500 to 2300 m.a.s.l.

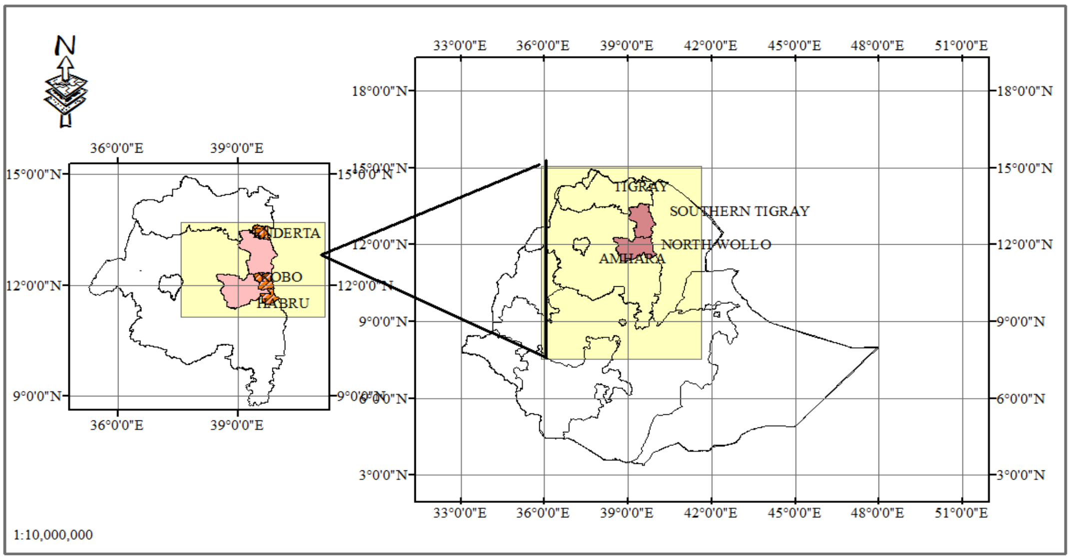

Figure 1. Map of study sites (Kobo, Sirinka and Enderta)

The study location has a semi-arid climatic condition, which has a general climatic feature of north eastern and eastern parts of Ethiopia. Based on the traditional climate classification system, the study sites lie Kola to Woynadega agro-ecological zones. More specifically, Kobo is categorized under Kolla; while Sirinka and Mekelle lies under Woynadega agro-ecology. Regarding rainfall distribution, Kobo and Sirinka has a bimodal rainfall pattern that gets a small rain from mid-February to mid-May (locally known as belg) and the main rain from June to September (known as kiremt). On the other hand, in Enderta and surrounding areas, rainfall is mono-modal type which receives rain from June to September except the small showers that occur during February to May. Table:1 depicts the seasonal and annual rainfall amounts and mean annual temperature of the study districts.

Table 1. Annual and seasonal rainfall and temperatures of the study area (based on 1985 to 2017 observed climate data for Kobo and Sirinka and 1980 to 2017 for Enderta district)

Site	Mean Temperature (°c)	Rainfall		
		Belg (mm)	*Kiremt* (mm)	*Annual* (mm)
Sirinka	20.1	300.1	586.5	1036.9
Kobo	22.6	117.3	401	699.9
Mekelle	15.3	81.5	517	607

2.2. Data and methods

Climate, soil physical and chemical characteristics, cultivar specific parameters, and field crop management data are are the minimum data sets required to simulate the model (Jones et al., 2003; Yakoub et al., 2017)

Soil Data:Soil data for the study districts were obtained from different sources. Soil profile data for Enderta district was obtained from Gebre et al., (2014) whereas, for Sirinka and Kobo areas 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 Zewdu et al., (2020).

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 National Meteorology Agency (NMA) of Ethiopia. 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 (WMO, 2003)

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(AgMIP, 2014). 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 (Ramirez-Villegas & Jarvis, 2010). 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 (Teshale and Melkam) and wheat (Mekele-1) were used as a testing crops. Teshale and Melkam sorghum varieties are released for dry lowland areas which frequent drought and water deficit are common. They are categorized early to medium maturity groups. Similarly, Mekele-1 is early maturing wheat variety recommended majorly for moisture and drought prone areas.

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 (Hoogenboom et al., 2010). DSSAT simulates growth and development of crops in response to weather, soil and crop management practices (Jones & Singels, 2008). For this study genetic coefficients for both sorghum and wheat cultivars were obtained from (Zewdu, 2016; and Zewdu et al; 2020).

Table 2. Estimated Genetic Coefficients values for Sorghum cultivars (Teshale and Melkam) at Kobo site, northern Ethiopia ((Zewdu et al., 2020)

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

Table 3: Estimated Genetic Coefficient values for wheat cultivar (Mekele-1)

GCs parameters	Definitions	Estimated Coef.
		Mekele-1
P1V	Days, Optimum vernalizing temperature, required for vernalization	8
P1D	Photoperiod response (% reduction in rate/10h drop in pp)	2.1
P5	Grain filling (excluding lag) phase duration (oC.d)	580.2
G1	Kernel number per unit canopy weight at anthesis (#/g)	49.8
G2	Standard kernel size under optimum condition (mg)	79.8
G3	Standard non stressed mature tiller wt (incl grain) (g dwt)	2.5
PHINT	Interval between successive tip appearance (oC.d)	150

Climate Change Adaptation

Crop production is affected biophysically by the changing climate such as rising temperature, changing rainfall regiomes and the increasing level of atmospharic carbon dioxide (Ouda et al., 2013). 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 (Ouda et al., 2013). In this study, planting window and fertilizer application rate were taken and evaluate as adaptation packages for this study.

Planting date: Three planting window windows which 16 to 30-June, 01 to 15-Jul and 16 to 30-July were assumed to evaluate the response of sorghum and wheat 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 scenario to investigate the performance of sorghum and wheat production also. Table 11 presents the nitrogen fertilization treatments used to determine the optimum nitrogen fertilization rate.

Table 4. fertilization rate (nitrogen) treatments for future sorghum and wheat production

	Treatment-1		**Treatment-2**		**Treatment-3**	
Nutrient Type	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 and wheat were simulated using both the base and the projected period. Finally, the performance of both crops with the prescribed changes was compared with the historic yield as follows.

$$\Delta yield = \frac{Y_{predicted} - Y_{base}}{Y_{base}} x100$$

; 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. Results 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 from 2.8% to 16.6% by 2050s and 8.4%-29% by 2080s. Variation of projected annual rainfall is observed across location, GCMs, and time periods. Regarding the study locations, annual rainfall is expected to be increased from 8.5-15.6% at Kobo, 12.2-16.6% at Sirinka and 2.4-8.4%, at Enderta by 2050s. Likewise, under 2080s, it is expected to increase 8.6-17.8%, 10-29% and 8.4-15.3% at Kobo, Sirinka and Enderta districts respectively. 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 8.7-13.6 % by 2050s and 3.1-32% by 2080s. In general, the projected rainfall is varied across locations, the GCMs used and growing season. According to (Funk et al., 2008), 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 (Moalafhi et al., 2005). In general, both June to September and annual rainfall total is expected to increase for mid and end periods for northern and north eastern region of Ethiopia.

Projected temperature

Projected temperature indicated that the study districts will experienced warmer temperature than today by 2050s and 2080s. On average, maximum temperature is expected to be increased by 1.8 °C by 2050s and 2.2 °C by 2080s under RCP4.5 emission scenario assumption; and 2.8°C to 3.8°C under the highest emission scenario. Similarly, night temperature is will be increased, on average, by 1.8°C and 2.4°C under RCP4.5 and by 2.7°C and 4.7°C under RCP8.5 by 2050s and 2080s respectively. The result further revealed that, maximum increase in temperature is expected under RCP8.5 emission scenario assumption relative of the counterpart.

Table 5. Projected change in temperature at Kobo, Sirinka and Enderta districts by by 2050s and 2080s

Station name	*Maximum temperature change (°C)*				*Minimum temperatures change (°C)*			
	2050s		*2080s*		*2050s*		*2080s*	
	RCP4.5	*RCP8.5*	*RCP4.5*	*RCP8.5*	*RCP4.5*	*RCP8.5*	*RCP4.5*	*RCP8.5*
Mekelle	*1.7*	*2.4*	*2.2*	*4.0*	*1.8*	*2.7*	*2.3*	*4.6*
Kobo	*1.8*	*2.3*	*2.1*	*4.0*	*1.7*	*2.7*	*2.4*	*4.7*
Sirinka	*1.8*	*2.4*	*2.3*	*3.4*	*1.8*	*2.8*	*2.4*	*4.7*
Average	***1.8***	***2.4***	***2.2***	***3.8***	***1.8***	***2.7***	***2.4***	***4.7***

3.2. Impacts of climate change on Wheat Vs Sorghum crops

Sorghum and wheat yield response for projected future climate is depicted in Figure 2. The result indicated that sorgum and wheat production in norther Ethiopia is negatively affected by the future climate. Accordingly, sorghum yield is projected be declined in the future. By 2080s, climate change is seriously affected sorghum production by 2080s. On the other hand, yield of wheat is projected to be increased in the future under RCP4.5 scenario assumption. Most studies clearly showed that elevated CO_2 is more benefited wheat production through stimulating photosynthesis and water use efficiency (WUE) whereas sorghum is least benefited elevated CO_2 relative to wheat (Zewdu et al., 2020).

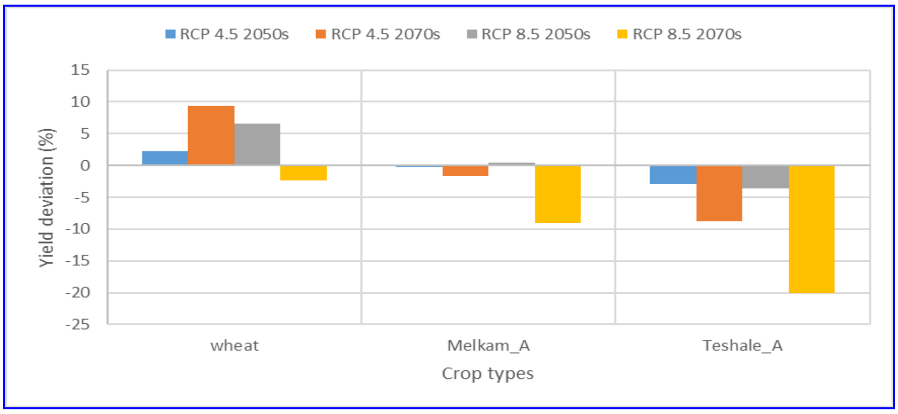

Figure 2. comparison of yield change for wheat and sorghum crops under the future climate

3.5. Evaluation of Adaptation Practices for Sorghum and Wheat Production

To reduce climate change uncertainties, following farming practices that better cope with the existing climate is most important and timely action if we need to sustain food production (UNFCCC, 2007;

Ahmad et al., 2020). Therefore, identifying best practices that stands with the changing climate is urgently needed. In this study, the performance of sorghum and wheat production for different ***planting date and fertilizer applicatio*****n** were evaluated under the projected future climate scenario using CERES-Sorghum and CERES-Wheat cropping system models (CSMs').

In rainfed crop production system, the key question is how we can sustain production under the changing and variable climate. Agrnomic management plays a significanrt role to determine vegetative, reproductive development, and final grain yield in general (Singh et al., 2012). In addition, to reduce the adverse impacts of climate change, evaluation and identification of appropriate adaptation practices are most significant to sustain production under the changing climate. Herewith, planting window and fertilizer application rate were evaluated and presented in below.

Planting Date

Adapting planting date is one of the strategy that designed to counterattack the negative impacts of climate change on crop production. Table 8 presents response of sorghum and wheat yield to different planting windows. The result revealed that, regardless of emission scenarios and the period considered, early planting (16-30 June) would give a better yield for both sorghum varieties at Kobo and Sirinka. However, delaying the planting dates beyond the normal would result in reduction of yield for both varieties at Kobo and Sirinka. On the other hand, early and late planting date at Mekelle would result yield penalty. However, normal planting date (01-15 July) is suggested for future production of wheat to cope the adverse impacts of climate change. The numbers in bracket shows deviation in yield in percent from the baseline yield.

Table 6 Sorghum yield response for early, normal and late planting at Kobo and Sirinka districts for mid (240-2069 and end (2070 to 2099) periods

			Simulated Yield (Yield Deviation %)			
		Planting	RCP4.5		RCP8.5	
Districts	Cultivar	window	MID	END	MID	END
Kobo	Melkam	Early	3333.9 **(15.9)**	3287.3 **(14.2)**	3249.6 **(13.1)**	2852.3 **(7.1)**
		Normal	3065.2 **(6.6)**	3067.4 **(6.6)**	3073.9 **(7.0)**	2477.1 **(-7.0)**
		Late	2543.9 **(-11.5)**	2559.7 **(-11.1)**	2605.6 **(-9.3)**	2038.4 **(-23.5)**
	Teshale	Early	3325.7 **(4.7)**	3204.7 **(4.2)**	3102.7 **(2.3)**	2495.3 **(-0.2**)
		Normal	3300.5 **(4.0)**	3191.8 **(3.8)**	3132.1 **(3.3)**	2551.7 **(2.0)**
		Late	2972.3 **(-6.4)**	2924.6 **(-4.9)**	2941.8 **(-3.0)**	2513.4 **(0.5)**
Sirinka	Melkam	Early	4434.1 (**11.4**)	4392.3 (**32.9**)	4387.5 (**11.2**)	3761.0 (**8.0**)
		Normal	4273.6 (**7.4**)	3982.5 (**22.6**)	4172.6 (**5.7**)	3545.6 (**1.8**)
		Late	3331.8 (**-16.3**)	3336.5 (**6.4**)	3665.9 (**7.1**)	3185.0 (**-8.5**)
	Teshale	Early	4337.0 (**10.8**)	4108.7 (**10.8**)	4331.4 (**4.0**)	3099.1 (**12.5**)
		Normal	3957.1 (**1.1**)	3743.6 (**1.0**)	4566.6 (**9.7**)	2733.3 (**-0.8**)
		Late	3394.4 (**-13.3**)	3282.7 (**-11.5**)	4254.9 (**2.2**)	2604.9 (**-5.5**)

Table 7 Wheat yield response for early, normal and late planting date for mid (240-2069 and end (2070 to 2099) periods

			Simulated Yield (Yield Deviation %)			
			RCP4.5		RCP8.5	
Districts	Cultivar	Planting window	MID	END	MID	END
Mekelle	Mekele-1	Early	1970.7 **(-2.2)**	2024.0 **(-6.1)**	2110.4 **(0.4)**	1845.9 **(-4.1)**
		Normal	2052.1 **(1.9)**	2137.7 **(-0.8)**	1735.0 **(-17.4)**	1905.1 **(-1.1)**
		Late	1598.0 **(-20.7)**	1771.8 **(-17.8)**	1414.1 **(-32.1)**	1718.5 **(-10.8)**

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 wheat and sorghum crops for different fertilization rates under projected future climate is portrayed in Figure 10. The result indicated that increasing of N fertilization rate would result in increased yield of both sorghum cultivars by 2050s and 2080s at Kobo and Sirinka. Applying 73 kg/ha of nitrogen fertilizer rate would result a decline in yield by 2080s for Teshale sorghum variety under both emission scenarios at the studied sites. In line with this, application of 73kg/ha of nitrogen would result a decline in yield for melkam variety by 2050s at Kobo and an increase of yield at Sirinka relative to 2080s.

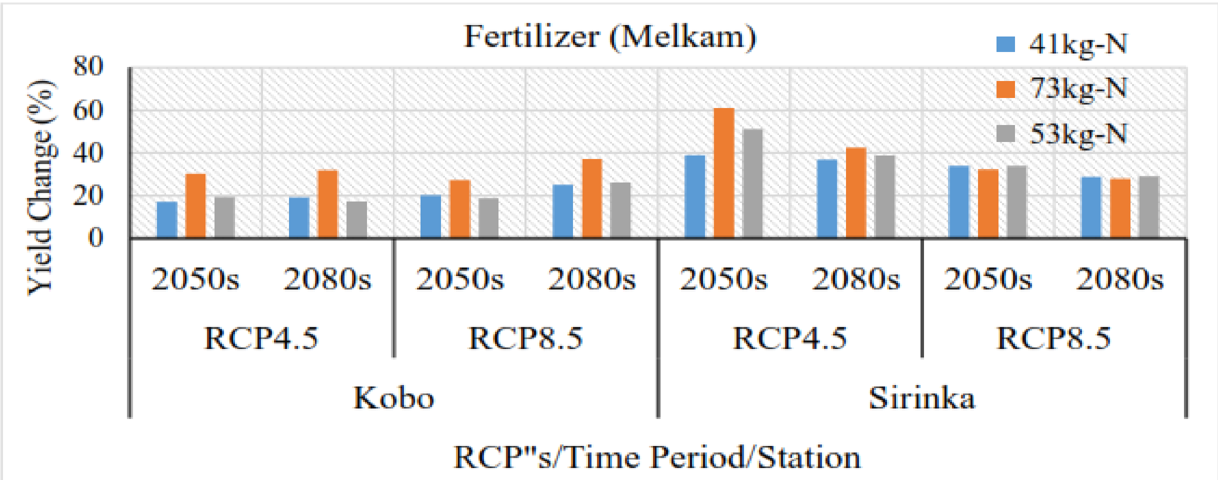

Figure 3. Yield response of sorghum (Melkam variety) for different fertilizer application rates by 2050s and 2080s under different emission scenarios at Kobo and Sirinka

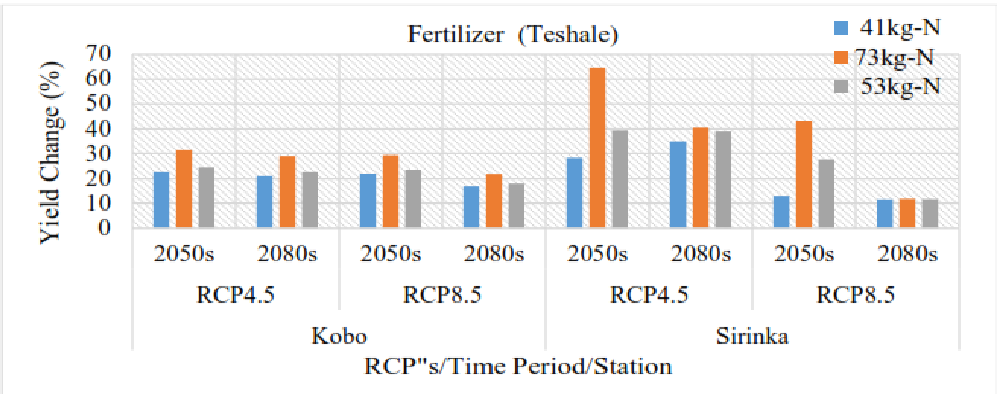

Figure 4. Yield response of sorghum (Teshale variety) for different fertilizer application rates under future climate conditions at Kobo and Sirinka

Similarly, the simulated result indicated that increasing nitrogen fertilizer rates gives a higher yield of wheat at Enderta study site. In this regard, application of 73kg/ha of nitrogen fertilizer would result a higher yield of wheat by 2050s than 2080s under both emission scenarios. In general, the model indicated that, increasing fertilization rate would play a significant role in maintaining or increasing yield under future climate conditions.

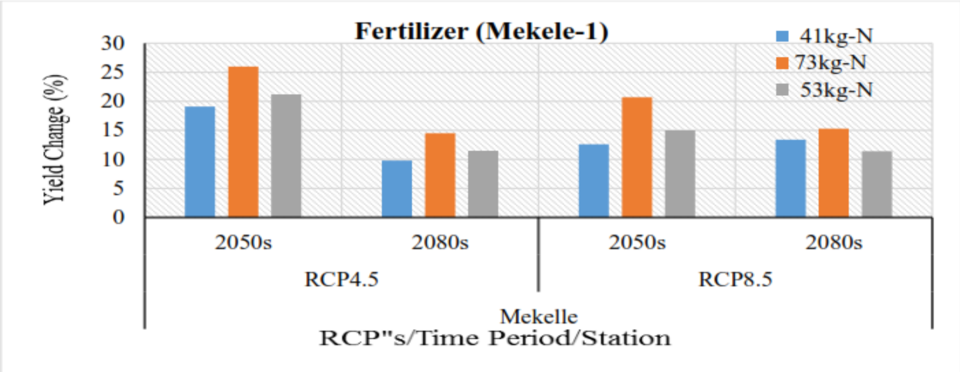

Figure 5. Yield response of wheat (Mekele-1) for different fertilizer application rates by 2050s and 2080s under different emission scenarios at Enderta

3.6. Summary and Conclusion

Recently, due to the growing concern of increasing 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, this study was conducted to evaluate and identify climate change adaptation practices that would increase yield of wheat and sorghum under the future climate. This study was conducted in three districts (Kobo, Sirinka and Mekelle) representing lowland and mid-highland agro-ecologies. Cropping system model, DSSATv4.8, was used to investigate potential adaptation practices for future sorghum and wheat production. Crop management practices; planting date and fertilizer application were evaluated under the projected climate scenarios. In addition, sensitivity of sorghum and wheat crops for different future climate scenarios was also evaluate using DSSAT4.8..

According to the result, the study districts will experienced warmer temperature in the future than today. On average, maximum temperature will be increased by 1.8°C and 2.2°C by 2050s and 2080s respectively under RCP4.5 emission scenario. The rate of warming is expected to be higher towards the end of the century in all districts considered for this study. Regarding rainfall, the result indicated that annual rainfall is expected to be increased on average by 2.8% to 16.6% and by 8.4%-29% by 2050s and 2080s, respectively. More specifically, conditioned on emission scenarios considered, annual rainfall at Kobo, Sirinka and Mekelle is expected to increase by 8.5-15.6%, 12.2-16.6% and 2.4-8.4% by 2050s respectively.

Moreover, results indicated that yield response for the future climate is varied among crops and varieties. Future production of sorghum would have drastically affected relative to wheat. The impact of future climate on sorghum and wheat production is varied with the types of emission scenarios, climate model and time period considered. However, on average, wheat yield is expected to be increased from 2.2-6.6% by 2050s. The result further revealed that early planting of sorghum could reduce and/or improve the production under the future climate. Moreover, nitrogen fertilizer application might be used to enhance sorghum and wheat production. Hence, field management practices such as changing planting date and nitrogen fertilization could be used as adaptation option to reduce the adverse impact of climate change in the study area.

Recommendation

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

- Assessment of climate change impacts on crop production as well as ecosystem service should consider multiple climate model (GCMs) to enhance predictability.
- Future policy options need to fine-tune climate change adaptation technologies based on agro-ecological settings
- 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
- 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

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. AgMIP. (2014). Guide for Running AgMIP Climate Scenario Generation tool with R. In *The Agricultural Imodel ntercomparison project* (Vol. 22, Issue 1). https://doi.org/10.2753/CES1097-14752201103
2. Ahmad, I., Ahmad, B., Boote, K., & Hoogenboom, G. (2020). Adaptation strategies for maize production under climate change for semi-arid environments. *European Journal of Agronomy*, *115*(June 2019), 126040. https://doi.org/10.1016/j.eja.2020.126040
3. Bekabil, U. T. (2014). *Review of Challenges and Prospects of Agricultural Production and Productivity in Ethiopia*. *4*(18), 70–78.
4. Boote, K. J. J., Jones, J. W. W., & Hoogenboom, G. (2008). Crop simulation models as tools for agro-advisories for weather and disease effects on production. *Journal of Agrometeorology*, *Part-1*(SPECIAL ISSUE 1), 9–17.
5. Bryan, E., Deressa, T., Gbetibouo, G. A., & Ringler, C. (2009). Adaptation to Climate Change in Ethiopia and South Africa : Options and Constraints. *Environmental Science & Policy*, *October 2017*.

https://doi.org/10.1016/j.envsci.2008.11.002

6. CSA, F. D. R. of E. C. S. A. (2018). *Federal Democratic Republic of Ethiopia: Central Statistical Agency Report on Area and Production of Major Crops*. *I*(586).
7. FAO. (2019). *Handbook on climate information for farming communities – What farmers need and what is available* (No. 184). Food and Agriculture Organization of United Nations.
8. FAO (Food and Agriculture Organization of the United Nations). (2012). Building resilience for adaptation to climate change in the agriculture sector. In A. N. and G. V. Meybeck A., Lankoski J., Redfern S. (Ed.), *Proceedings of a Joint FAO/OECD Workshop 23–24 April 2012*. Food and Agriculture Organization. www.fao.org/docrep/017/i3084e/i3084e.pdf
9. FAO, F. and A. O. of the U. N. (2012). *Natural Resource Assessment for Crop and Land Suitability : An application for selected bioenergy crops in Southern Africa region* (A. Kassam, N. Lutaladio, T. Friedrich, E. Kueneman, M. Salvatore, M. Bloise, & J. Tschirley (eds.); Vol. 14). Plant Production and Protection division of Food and agriculture organization oF the united nations.
10. FAO, F. and A. O. of the U. N. (2015). *Adaptation to climate risk and food security Evidence from smallholder farmers in Ethiopia* (Issue February).
11. FAO, F. and A. O. of the U. N. (2016). *Ethiopia Climate-Smart Agriculture Scoping Study* (E. Jirata, M., Grey, S. and Kilawe (ed.)). Food and Agriculture Organization.
12. Funk, C., Dettinger, M. D., Michaelsen, J. C., Verdin, J. P., Brown, M. E., Barlow, M., & Hoell, A. (2008). Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. In *Proceedings of the National Academy of Sciences of the United States of America* (Vol. 105, Issue 32). https://doi.org/10.1073/pnas.0708196105
13. Georgis, K., Dejene, A., & Malo, M. (2009). *Agricultural based Livelihood Systems in Drylands in the Context of Climate Change : Inventory of Adaptation Practices and Technologies of Ethiopia*. 1–44.
14. Giorgis;, K., Tesfaye;, A., & Assefa, G. (2018). *Agricultural Drought-Prone Areas of Ethiopia : Interventions, Challenges and Good Practice* (Issue September).
15. Hoogenboom, G., Jones, J. ., Porter, C. ., Wilkens, P. ., Boote, K. ., Hunt, L. ., & Tsuji, G. . (2010). Decision Support System for Agrotechnology Transfer Version 4.5. Volume 1: Overview. In G. Hoogenboom, J. W. Jones, C. H. Porter, P. W. Wilkens, K. J. Boote, L. A. Hunt, & G. Y. Tsuji (Eds.), *Agricultural Systems* (Vol. 1). University of Hawaii, Honolulu, HI.
16. IFPRI, I. F. P. R. I. (2010). *Micro-level Practices to Adapt to Climate Change for African Small-scale Farmers: A Review of Selected Literature* (T. Below, A. Artner, R. Siebert, & S. Sieber (eds.); IFPRI Discussion Paper 00953; Issue February). International Food Policy Research Institute. ifpri-copyright@cgiar.org.%0A
17. Irish AID. (2018). *Ethiopia Country Climate Risk Assessment Report*. cli-mathttps://www.climatelearningplatform.org/change team;%0A
18. Jones, J. ., He, J., Boote, K. ., Wilkens, P., & Porter, C. . (2010). *Estimating DSSAT Cropping System Cultivar-Specific Parameters Using Bayesian Techniques*.
19. Jones, J. . W., Hoogenboom, G., Porter, C. . H., Boote, K. . J., Batchelor, W. . D., Hunt, L. . A., Wilkens, P. . W., Singh, U., Gijsman, A. . J., & Ritchie, J. T. . . (2003). The DSSAT cropping system model. *European Journal of Agronomy*, *18*(3–4), 235–265. https://doi.org/10.1016/S1161-0301(02)00107-7
20. Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., Wilkens, P. W., Singh, U., Gijsman, A. J., & Ritchie, J. T. (2003). The DSSAT cropping system model. In *European Journal of Agronomy* (Vol. 18, Issues 3–4). https://doi.org/10.1016/S1161-0301(02)00107-7

21. Jones, M., & Singels, A. (2008). DSSAT v4 . 5 - Canegro Sugarcane Plant Module Scientific documentation. In *South African Sugarcane Research Institute Mount* (Issue December, pp. 1–34).
22. MoA, M. of A. (2011). *Agriculture Sector Programme of Plan on Adaptation to Climate Change* (Issue September).
23. Moalafhi, D. B., Kenabatho;, P. K., & Parida, B. P. (2005). Climate variability and change in Africa. In on-athan I. Matondo;, W. J. P. Sandwidi;, & B. F. Alemaw (Eds.), *Acta Zoologica Lituanica* (Vol. 15, Issue 2). Springer Nature. https://doi.org/10.1080/13921657.2005.10512382
24. NMA, N. M. A. (2007). *Climate Change National Adaptation Programme of Action (NAPA) of Ethiopia* (Issue June).
25. Ouda, S., El-Afandi, G., & Noreldin, T. (2013). Modeling Climate Change Impacts and Adaptation Strategies for Crop Production in Egypt: An Overview. *Handbook of Environmental Chemistry*, *25*(May), 99–120. https://doi.org/10.1007/698_2013_226
26. Ramirez-Villegas, J., & Jarvis, A. (2010). *Downscaling Global Circulation Model Outputs: The Delta Method Decision and Policy Analysis Working Paper No. 1* (No. 1; Issue 1).
27. Singh, P., Boote, K. J., Kumar, U., Srinivas, K., Nigam, S. N., & Jones, J. W. (2012). Evaluation of Genetic Traits for Improving Productivity and Adaptation of Groundnut to Climate Change in India. *Journal of Agronomy and Crop Science*, *198*(5), 399–413. https://doi.org/10.1111/j.1439-037X.2012.00522.x
28. Singh, P., Nedumaran, S., Traore, P. C. S., Boote, K. J., Rattunde, H. F. W., Prasad, P. V. V., Singh, N. P., Srinivas, K., & Bantilan, M. C. S. (2014). Quantifying potential benefits of drought and heat tolerance in rainy season sorghum for adapting to climate change. *Agricultural and Forest Meteorology*, *185*, 37–48. https://doi.org/10.1016/j.agrformet.2013.10.012
29. UNFCCC, U. N. F. C. on C. C. (2007). *Impact, Vulnerabilities and Adaptation*.
30. WMO. (2003). Agrometeorology Related to Extreme Events. In H. P. Das, T. I. Adamenko, K. A. Anaman, R. G. Gommes, & G. Johnson (Eds.), *World Meteorological Organization* (WMO-No. 94, Issue 201). World Meteorological Organization. https://doi.org/10.1017/S0020818300013011
31. WMO, W. M. O. (2004). Strengthening Operational Agrometeorological Services at the National Level. In R. P. Motha, M. V. K. Sivakumar, & Michele Bernard (Eds.), *Proceedings of the Inter-Regional Workshop March 22-26, 2004, Manila, Philippines*. World Meteorological Organization Agricultural Meteorology Division.
32. World Bank. (2011). *Climate Risk and Adaptation Country Profile of Ethiopia: Vulnerability, Risk Reduction, and Adaptation to Climate Change* (Issue April).
33. Yakoub, A., Lloveras, J., Biau, A., Lindquist, J. L., & Lizaso, J. I. (2017). Field Crops Research Testing and improving the maize models in DSSAT : Development , growth , yield , and N uptake. *Field Crops Research*, *212*(June), 95–106. https://doi.org/10.1016/j.fcr.2017.07.002
34. Zewdu, E. (2016). *ASSESSING IMPACT OF CLIMATE CHANGE ON SORGHUM (Sorghum bicolor L.) AND WHEAT (Triticum aestivum L.) PRODUCTION IN NORTHERN ETHIOPIA* (Issue November). Haramaya University.
35. Zewdu, E., Hadgu, G., & Nigatu, L. (2020). Impacts of climate change on sorghum production in North Eastern Ethiopia. *Changes*, *14*(February), 49–63. https://doi.org/10.5897/AJEST2019.2803