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Modeling the Potential Impact of Climate Change on Cotton (*Gossypium hirsutum*) Production in Northeastern Semi-Arid Afar and Western Tigray Regions of Ethiopia

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Abstract

Cotton (*Gossypium hirsutum*) is a globally important fiber plant. Impact of climate change and variability is already being felt in Ethiopia in the form of higher temperature, erratic nature of rains (spatially and temporally), floods and drought. The aim of this study was to characterize the climate of the study areas, analyze the impact of climate change on cotton production and to recommend suitable adaptation strategies for cotton production under changing climate at Amibara, Dansha and Kebabo areas of Ethiopia. Historical climate data during 1980-2010, were collected from National Meteorological Agency and National aeronautical space administration while soil and cotton experimental data of the study areas were collected from respective agricultural research center. DSSATV4.6 model was calibrated and evaluated to assess the possible impact of climate change on cotton yield under the baseline and future climate. Model performance was assessed statistically by using quantitative statistical indicators: coefficient of de-term ination (R^2), root mean square error (RMSE) and index of agreement (IA). In order to estimate the level of climate change impact (rainfall and temperature) on cotton production for the study areas, two Representative path ways as a three-time segment: Near-term i.e., 2010-2039, Mid-term i.e., 2040-2069) and End-term i.e., 2070-2099 using the coupled atmosphere-ocean HadGEM2-ES GCMs model. Time series anomaly plots for temperature showed that the mean temperature over Amibara, Dansha and Kebabo has increased by about 0.5 to-2ºC, 0.5 to 1.65ºC and 0.5 to 1.5ºC and rainfall showed slight variability in start and end of season during the period of 1980-2010. The projected temperature and rainfall pattern shows that an overall increasing trend in annual temperature and significant variation of monthly and seasonal rainfall from the historical period of time. The rainfall varies between-1.6 to 3.3%,-0.7 to 3.8% and-0.8 to 3.3% at Amibara, Dansha and Kebabo respectively. Climate change analysis indicated a strong influence of temperature on cotton production in Amibara and Dansha sites and yield will be substantially decreased on average by 12% to 13% with projected increasing temperature and erratic nature of rainfall. Projected model simulations predict that climate change will shift planting dates towards late planting (May 15 and July 15) for the period of 2010-2099 at Amibara and Dansha while for Kebabo site early planting June 15 is preferable. In general cotton yield, will decrease but, late planting date and further research on different agronomic management practices will result in increased yield for Amibara and Dansha.

Keywords: Adaptation strategies; Cotton; Climate characterization; DSSATV4.6; GCM; Instat+3.37

Introduction

General background

Cotton is an agro-industrial crop produced in both developing and developed countries. It accounts for more than half of all fibers used in clothing and household furnishings [1]. The largest volume of cotton production in the world is concentrated in countries like China, United States, India, Pakistan and Brazil. And yet low income countries in Sub-Saharan Africa (Benin, Burkina Faso, Chad) and other similarly poor countries elsewhere in the world depend heavily on cotton for earning foreign exchange [2].

Agriculture is the main source of Ethiopian economy and provides direct livelihood for about 83% of the population contributing 45% of the country's gross domestic product (GDP), 87% of export earnings and around 73% of the raw material for agro-processing industries [3]. However, the amount of cotton exported and the amount of revenue generated from the export is very low [4]. Despite its potential capacity to produce abundant cotton, Ethiopia performed weakly in its exports of textile and garment products. This situation shows that the country is receiving insignificant benefits from its cotton and textile products export [5]. It is important, therefore, to study factors that are responsible for such low production and benefits.

Climate change will impact disproportionately on poorer African countries. The impacts of climate change on Africa's agricultural systems will most likely result from increased intra-annual (seasonal) and inter-annual climate variability and from an increased frequency of extreme events than from changes in mean climatic conditions and agricultural yields will continue to decline with rising temperature [6].

Statement of the problem

According to WMO approximately 70 percent of Africans or close to 700 million people rely on farming for their livelihood and over 95 percent of it is rainfed [7]. Changing weather patterns due to climate

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change are therefore expected to reduce agricultural yields in some areas by as much as 50 percent as early as 2020. Agricultural production is the most sensitive to climate because it depends for its production process on natural heat for energy and on water, both climate-related variables. This reinforces the need for the region to consider long-term constraints that any future climate changes may place on agriculture [8].

Though little is known so far, climate change impacts on cotton growth and development that influence yield and fiber quality is the result of increasing in temperature, reduced water availability and increased in atmospheric evapotranspiration and the changing rainfall levels are affecting cotton yields. Amibara, Dansha and Kebabo is the main cotton production areas in Ethiopia but there is no significant research conducted yet on the impact of climate change on cotton growth, development and on cotton yield in the three study areas (Amibara, Dansha and Kebabo).

Research objectives

General objective of the study: The main objective of this study is to investigate and analyze the impact of climate variability and change on cotton production using historical climate data and future climate projections. In addition to show climate adaptation strategies due to changing planting dates in two semi-arid regions of Ethiopia particularly in the Afar and Western Tigray regions, of Ethiopia.

Specific objectives:

1. To characterize and assess the seasonal climate variability of the past 30 years and to project future climate trends of the study areas.

2. To analyze climate change impact on future cotton production for the study areas.

3. To recommend appropriate adaptation strategies under changing climate for the study areas.

Material and Methods

Location

The study was carried out in Middle Awash of Afar regional state Amibara Wereda, Dansha and Kebabo of Western Tigray region for the reason that both study sites grow cotton in large quantities. Amibara is located 250 km Northeast part from Addis Ababa the capital city of Ethiopia. Its geographical location is 9.26°N to 9.45°N latitude and 40.15°E to 40.25°E longitude and 740 m.a.s. l (Figure 1).

Based on the 2007 census conducted by the central statistical Agency of Ethiopia, Amibara Wereda has a total population of 63,378, of whom 35,374 are men and 28,004 women Among the total population 68.86% are Muslim, 21.2% are Orthodox Christians, and 9.18% are Protestants. Tsegede Wereda has a total population of 103,852 of whom 52,763 are men and 51,089 women [9].

Techniques of baseline climate characterization for Amibara, Dansha and Kebabo

The historical daily climate data such as maximum, minimum temperature, rainfall, and sunshine hours both observed and gridded data were collected from National Meteorological Agency of Ethiopia starting from 1980 to 2010, AgMERRA data from NASA and also from the records of Werer Agricultural Research Center (WARC). The daily climate data was captured into Microsoft Excel 2010. In order to make the series acquiescent to further analyses, the missing data were checked using Excel sheet.

Analysis of the impact of climate change on cotton production

AgMIP SSA (Sub-Saharan Africa) integrated regional assessments have used the same 5 GCMs for consistency among regions and therefore require to be used in all locations in Sub-Saharan Africa. The GCMs such as (CCSM4 (E), GFDL-ESM2M (I), HadGEM2-ES (K), MIROC5 (O), MPI-ESM-MR (R) were selected to be used in all farms widely due to their recentness, consistency of processes and resolution-performance in monsoon regions [10]. In addition, AgMIP team of Mekelle University compared HAdGEM2-ES to other 20 GCM's and hence, was able to consistently predict rainfall at an average of the study area.

Therefore, HadGEM2-ES climate model was chosen for predicting future rainfall and temperature of Amibara, Dansha and Kebabo and DSSAT v4.6 was used to analyze the possible impact of the future climate change on cultivar of cotton yield production over Amibara, Dansha and Kebabo. The input required for impact analyses of CMIP5 procedure for three-time period and two RCPs based on GCM "HadGEM2-ES" were generated from historical data by using AgMIP project script. Therefore, the climate change scenarios of rainfall and temperature were projected for representative concentration pathways of both RCP4.5 and RCP8.5 for Near-term 4.5 (2010-2039), Near-term 8.5 (2010-2039), Mid-term 4.5 (2040-2069), Mid-term 8.5 (2040-2069), End-term 4.5 (2070-2099) and End-term 8.5 (2070-2099) times respectively.

Results and Discussion

Baseline and projected climate characterization for Amibara, Dansha and Kebabo

Baseline rainfall pattern for Amibara, Dansha and Kebabo (1980-2010): The mean annual and seasonal baseline rainfall for the last 30 years (1980-2010) in Amibara, Dansha and Kebabo is shown in Figure 2. The annual mean rainfall was 909 mm, 741 mm, and 566 mm for Kebabo, Dansha and Amibara respectively while the rainfall pattern was highly variable from season to season and from year to year. Though Dansha and Kebabo are located in vicinity, variable rainfall was observed as supported by Hadgu [11]. who conducted research in different parts of Tigray region and found that high inter-annual variability of coefficient of variation of rainfall in Alamata, Adigudum, Mekelle, Edagahamus and Adigrat towns.

Baseline rainfall anomalies for Amibara, Dansha and Kebabo: The rainfall anomaly over Amibara, Dansha and Kebabo shows that highly variable from year to year for the last periods. The annual Kiremt (JJAS) seasonal rainfall trend shows that both positive and negative anomalies for the last 30 years (1980-2010). The upward bar shows positive anomalies indicating that the rainfall was above the mean value and these years were wetter years while the downward bar shows negative anomalies indicating the rainfall was below normal from mean rainfall over Amibara, Dansha and Kebabo.

Projected rainfall pattern for Amibara, Dansha and Kebabo (2010-2099): The projected rainfall pattern for Amibara, Dansha and Kebabo is presented in Table 1. It is observed that the projected rainfall at Amibara decreases by-1.648% and-4.349% during Near-term 4.5 and Mid-term 4.5 respectively. While the rainfall increases during Near-term 8.5, Mid-term 8.5, End-term 4.5 and End-term 8.5 by 4.175%, 3.097%, 0.214% and 2.27% respectively. The projected rainfall over Dansha shows that erratic nature from baseline rainfall. The rainfall decreases by-1.27%,-0.65% and-0.58% for Near-term 4.5, Near-term 8.5 and Mid-term 4.5 periods respectively. The rainfall increases relatively

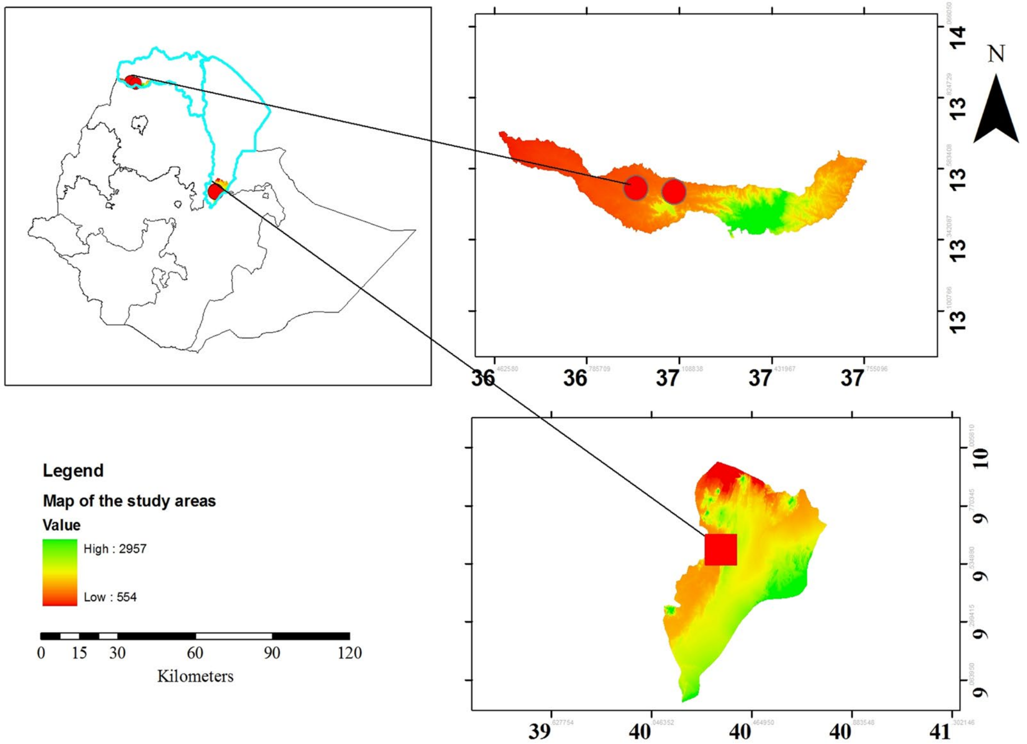

Figure 1: Map of the study areas of Amibara, Dansha and Kebabo.

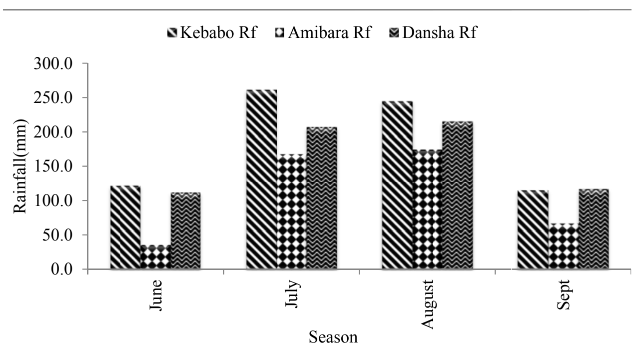

Figure 2: Kiremt seasonal rainfall amount for Amibara, Dansha and Kebabo.

during Mid-term 8.5, End-term 4.5 and End-term 8.5 scenarios by 3.84%, 0.30% and 1.33% respectively. The projected rainfall for Kebabo shows slight decreasing in amount from baseline rainfall during the periods of 2010-2099. The rainfall decreases by-0.8%,-1.1%,-4.8%,-0.1%, and-3.2% during the periods of Near-term 4.5, Near-term 8.5, Mid-term 4.5, Mid-term 8.5 and End-term 4.5 scenarios respectively. While the rainfall increase by 3.3% during End-term 8.5 scenario at Kebabo.

Generally, the projected rainfall pattern for the three places shows that the rainfall slightly increases for the period of RCP8.5 as compared to RCP4.5 and the current rainfall amount. This is similar with Collins report of CMIP5 model shows a gradual increase in global precipitation over the 21st century [12]. The rainfall percentage change exceeds 0.05 mm/day (~2% of global precipitation) and 0.15 mm/day (~5% of global precipitation) by 2100 in RCP2.6 and RCP8.5 respectively.

According to Bates and Kundzewicz, Fowler and Blenkinsop reported that unlike to the minimum and maximum temperature, precipitation could not able to replicate the historical (observed) data. [13,14]. This is due to complicated nature of precipitation processes and its distribution in space and time. In addition to this, Thorpe confirmed that climate model simulation for precipitation have been improved over time but is still a problematic and also added that rainfall predictions have a larger degree of uncertainty than those for temperature [15]. This is because rainfall is highly variable in space and so the relatively coarse spatial resolution of the current generation of climate models is not adequate to fully capture that variability. Therefore, the present study provided only a clue about the future precipitation of the area and opens a window for researchers and policy makers to conduct further research by using different GCMs.

Projected maximum temperature for Amibara, Dansha and Kebabo (2010-2099): Temperature is one of the major environmental factors affecting the growth, development and yields of cotton crops, especially the rate of development. [16]. The projected maximum temperature for the period of 2010 to 2099 increases for Amibara, Dansha and Kebabo relative to baseline maximum temperature (Table 2).

Cotton production with different planting dates under future climate change scenarios at Amibara

The simulated cotton yield at Amibara decreased during early and normal planting dates in the future periods while delayed planting date relatively increases the future cotton yield (Table 3).

At Amibara the projected future cotton yield decreased more with early planting compared to the corresponding historical yield as presented in (Table 3). Yield change due to early planting date under RCP4.5 is-16.51%,-16.97% and-8.61% for the period of near-

Table 1: Projected mean annual rainfall for Amibara, Dansha and Kebabo under RCP 4.5 and 8.5 RCPs.

Sites	Scenario	Projected mean Rainfall (mm)	Change of Rf (%)	Baseline Rf (mm)
Amibara	Near term 4.5RCP	567.8	-1.6	577.34
	Near term 8.5RCP	601.4	4.2	
	Mid term 4.5RCP	552.2	-4.3	
	Mid term 8.5RCP	595.2	3.1	
	End term 4.5RCP	578.6	0.2	
	End term 8.5RCP	590.5	2.2	
Dansha	Near term 4.5RCP	756.3	-1.3	766
	Near term 8.5RCP	761.1	-0.7	
	Mid term 4.5RCP	761.6	-0.6	
	Mid term 8.5RCP	795.4	3.8	
	End term 4.5RCP	768.3	0.3	
	End term 8.5RCP	776.2	1.3	
Kebabo	Near term 4.5RCP	902.2	-0.8	909.92
	Near term 8.5RCP	900.2	-1.1	
	Mid term 4.5RCP	866	-4.8	
	Mid term 8.5RCP	909.1	-0.1	
	End term 4.5RCP	880.7	-3.2	
	End term 8.5RCP	940.1	3.3	

Table 2: Projected maximum temperature change under different scenarios for Amibara, Dansha and Kebabo. T_{max}: Maximum temperature.

Sites	Scenario	Projected maximum temperature (oC)	Tmax change (°C)	Baseline Tmax (°C)
Amibara	Near term 4.5RCP	35.7	1.3	34.39
	Near term 8.5RCP	35.7	1.3	
	Mid term 4.5RCP	36.8	2.5	
	Mid term 8.5RCP	37.5	3.1	
	End term 4.5RCP	37.5	3.1	
	End term 8.5RCP	39.3	4.9	
Dansha	Near term 4.5RCP	36.6	1.3	35.34
	Near term 8.5RCP	36.9	1.5	
	Mid term 4.5RCP	37.6	2.3	
	Mid term 8.5RCP	38.5	3.1	
	End term 4.5RCP	38.4	3.1	
	End term 8.5RCP	40.7	5.4	
Kebabo	Near term 4.5RCP	32	1.3	30.67
	Near term 8.5RCP	32.1	1.4	
	Mid term 4.5RCP	33.3	2.6	
	Mid term 8.5RCP	33.9	3.2	
	End term 4.5RCP	34.1	3.5	
	End term 8.5RCP	36	5.3	

term, mid-term and end-term respectively. Similarly cotton yield decreased under RCP8.5 for the respective time periods by-18.06%,-19.53% and-20.32% yields will decrease. The percentage yield change for normal planting under RCP4.5 for near, mid and end-term time period is-9.4%,-10.2 and-10.1% yield will decrease from the baseline. Whereas for RCP8.5 cotton yield will decrease more at the time of normal planting by-10.7%,-14.3% and-16.1%. The projected future yield relatively increased with delayed planting compared to historical yield. The cotton yield relatively increased when late planting date was used under RCP4.5 by 1.71%, 1.20%, and 0.5% for the near, mid and end-term period. Similarly cotton yield increased when late planting date was used for the respective time periods by 0.4% and 0.2% for Near-term 8.5 and Mid-term 8.5 while yield relatively decreases by-2.20% under End-term 8.5 scenario. In contrast with early and normal planting dates for the period of 2010-2099 at Amibara the yield slightly increased by using late planting date under both RCP scenarios. It should however be noted that yields change was simulated by assuming that the necessary inputs such as fertilizers and different seeds variety and the soil conditions do not change. According to Ali report cotton yield affected by different sowing dates under the climatic conditions of Vehari, Pakistan and concluded that the highest seed cotton yield of 2039 kg/ ha was obtained on 15th May [17].

Generally, the result shows that future cotton yield at Amibara decreased due to the negative impact of climate change. This finding is similar with the findings of Reddy reported that a decreased in cotton yield of 3–37% resulting from expected climate change in cotton belt countries of Southern United States [18]. Moreover, inconsistencies in the prediction of cotton yield changes due to climate change (including CO_2 enrichment) were reported by Doherty [19].

Buttar conducted research on irrigated cotton of India's Punjab region by using CropSyst model and reported that the future warming could reduce seed cotton yield through accelerated development and hence shorter growth duration [20].

Table 3: Statistical summary of simulated cotton yield for early, normal and late planting date for Amibara, EP: Early planting, NP: Normal planting and LP: Late planting SD: Standard deviation and CV: Coefficient of variation.

Amibara					
Descriptive statistics					
Planting dates	**Scenarios**	**Mean yield (kg/ha)**	**SD**	**CV**	**% of yield change**
EP March15	**Baseline**	**4826**	**509**	**0.11**	
	Near term 4.5RCP	4029	449	0.11	-16.51
	Mid term 4.5RCP	4007	424	0.11	-16.97
	End term 4.5RCP	4410	366	0.08	-8.61
	Near term 8.5RCP	3954	409	0.1	-18.06
	Mid term 8.5RCP	3883	359	0.09	-19.53
	End term 8.5RCP	3845	297	0.07	-20.32
NP April15	**Baseline**	**5544**	**415**	**0.07**	
	Near term 4.5RCP	5025	479	0.09	-9.4
	Mid term 4.5RCP	4980	519	0.1	-10.2
	End term 4.5RCP	4985	541	0.11	-10.1
	Near term 8.5RCP	4948	397	0.08	-10.7
	Mid term 8.5RCP	4750	523	0.11	-14.3
	End term 8.5RCP	4650	385	0.08	-16.1
LP May 15	**Baseline**	**5879**	**325**	**0.05**	
	Near term 4.5RCP	5980	402	0.07	1.71
	Mid term 4.5RCP	5950	523	0.08	1.2
	End term 4.5RCP	5910	404	0.07	0.53
	Near term 8.5RCP	5905	373	0.06	0.44
	Mid term 8.5RCP	5892	529	0.09	0.22
	End term 8.5 RCP	5750	579	0.1	-2.2

Table 4: Statistical summary of simulated cotton yield for early, normal and late planting date for Dansha, EP: Early planting, NP: Normal planting and LP: Late planting SD: Standard deviation and CV: Coefficient of variation.

Dansha					
Descriptive statistics					
Planting date	**Scenario**	**Mean yield (kg/ha)**	**SD**	**CV**	**% of yield change**
EP June15	**Baseline**	**6053**	**460**	**0.08**	
	Near term 4.5RCP	6029	398	0.07	-0.4
	Mid term 4.5RCP	5814	616	0.11	-3.9
	End term 4.5RCP	4841	634	0.13	-20
	Near term 8.5RCP	6053	460	0.08	0
	Mid term 8.5RCP	4914	616	0.13	-18.8
	End term 8.5RCP	4677	367	0.07	-22.7
NP June25	**Baseline**	**5500**	**396**	**0.07**	
	Near term 4.5RCP	5496	339	0.06	-0.08
	Mid term 4.5RCP	4337	499	0.12	-21.1
	End term 4.5RCP	4471	461	0.1	-18.7
	Near term 8.5RCP	5560	396	0.07	1.09
	Mid term 8.5RCP	4337	499	0.12	-21.1
	End term 8.5RCP	4450	410	0.09	-19.09
LP July15	**Baseline**	**4967**	**293**	**0.06**	
	Near term 4.5RCP	4987	314	0.06	0.72
	Mid term 4.5RCP	4252	538	0.13	0.86
	End term 4.5RCP	4276	447	0.1	-0.06
	Near term 8.5RCP	4967	293	0.06	1.25
	Mid term 8.5RCP	4252	538	0.13	0.52
	End term 8.5RCP	4152	316	0.07	-0.27

Cotton production with different planting dates under future climate change scenarios at Dansha: The simulated cotton yield at Dansha shows that the yield decreases up to 22% in the coming periods during early and normal planting dates. The future yield comparatively increases by using late planting date of July 15 (Table 4).

Cotton production with different planting dates under future climate change scenarios at Kebabo: At Kebabo site the simulated cotton yield shows that in the coming periods the yield increases in all planting dates except during late planting date of Near-term 4.5 scenarios. The cotton yield increased up to 42% and only decreases

Table 5: Statistical summary of simulated cotton yield for early, normal and late planting date for Kebabo.EP: Early planting, NP: Normal planting and LP: Late planting SD: Standard deviation and CV: Coefficient of variation.

Kebabo					
Descriptive statistics					
Planting dates	**Scenario**	**Mean yield (kg/ha)**	**SD**	**CV**	**% of yield change**
EP June15	**Baseline**	**4417**	**430**	**0.09**	
	Near term 4.5RCP	4704	560	0.12	6.5
	Mid term 4.5RCP	5733	339	0.06	29.8
	End term 4.5RCP	6217	363	0.06	40.8
	Near term 8.5RCP	4880	488	0.1	9.5
	Mid term 8.5RCP	6013	273	0.05	36.1
	End term 8.5RCP	6285	527	0.08	42.3
NP June25	**Baseline**	**4220**	**403**	**0.09**	
	Near term 4.5RCP	4538	461	0.1	7.5
	Mid term 4.5RCP	5342	397	0.07	26.6
	End term 4.5RCP	5987	345	0.05	41.9
	Near term 8.5RCP	4592	407	0.08	8.8
	Mid term 8.5RCP	5748	279	0.04	36.2
	End term 8.5RCP	6026	462	0.07	42.8
LP July15	**Baseline**	**4106**	**486**	**0.12**	
	Near term 4.5RCP	3967	423	0.11	-3.4
	Mid term 4.5RCP	4799	320	0.07	16.9
	End term 4.5RCP	5417	289	0.05	31.9
	Near term 8.5RCP	4172	311	0.07	1.6
	Mid term 8.5RCP	5227	301	0.06	27.3
	End term 8.5RCP	5577	324	0.06	35.8

by-3.4% during the periods of Neartem 4.5 from the current yield at Kebabo (Table 5).

Conclusion and Recommendations

The analyzed historical long-term climate data shows that there was variability in rainfall on the start and end of season for the three study areas (Amibara, Dansha and Kebabo). The projected rainfall for Amibara demonstrates slight variability over all scenarios. The rainfall at this site decreased by-1.64% to-4.34% over the near-term and an increase by 0.24 to 2.27% over the end-term. While the projected maximum temperature at Amibara site showed an increase between 1.3°c in the near-term and 4.8°c in the end-term compared to the baseline. Projected rainfall at Dansha decreases by-1.27%,-0.65% and-0.58% during Near-term 4.5, Near-term 8.5 and Mid-term 4.5 periods respectively. The future maximum temperature is very high during Mid-term 4.5, Mid-term 8.5, End-term 4.5 and End-term 8.5, scenarios at Dansha.

1. Emphasis should be put on modeling development, growth and yield of different cotton cultivars under different climatic conditions of semi-arid and arid regions of Ethiopia.
2. Sowing time of cotton plant needs to be re-investigated at different agro-ecological zones over semi-arid regions of Ethiopia including the study areas.
3. Strengthen of further research on cotton productivity and impact of climate change in the future time by using different GCMs models.

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