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Enhancing Lentil *(Lens culinaris* Medikus*)* Production via Adaptation Measures under Climate Projection in Central Highlands of Ethiopia

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Aim: The study was carried out with the specific objective to identify the best adaptation measure for lentil production under projected climate change in central highlands of Ethiopia.
Methodology: Baseline climate data were collected from the National Meteorological Agency of Ethiopia; whereas the projected climate data (for the period 2030s and 2050s) were downscaled using six ensembled climate models, namely: BCC-CSM1-1, CSIRO-Mk3-6-0, HadGEM2-ES, MIROC-ESM, MIROC-ESM-CHEM, and MIROC5, under two representative concentration pathways (RCPs): RCP4.5 and RCP8.5. Crop data, such as yield, yield components and other crop management data, were obtained from Debre Zeit Agricultural Research Center (DZARC). DSSAT model was employed to assess the impacts of projected climate on lentil prodcution, and to identify the best adaptation measure.
Results: The results of the study revealed that sowing date, plant density, and row spacing would significantly influence the yields of Alemaya X FLIP 88-41L-02-AK-14 and Alemaya genotypes. The highest (26%) yield increase for genotype Alemaya X FLIP 88-41L-02-AK-14 would be noticed if planted in the 2nd decade of June with CO_2 fertilization by 2030s under RCP8.5. In contrast, the highest (11.5%) yield reduction for same genotype would be expected by 2050s without CO_2

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fertilization under RCP4.5, if planted early in June. Similarly, the highest (19.7%) yield increase for Alemaya genotype would be expected under RCP8.5 scenario with CO_2 fertilization by 2050s; planting early in June would rather decrease the yield. The research results also showed that the highest (16%) yield increase would be experienced if planted with a density of 100 plants per square metre for Alemaya X FLIP 88-41L-02AK-14 genotype under RCP8.5 scenario by 2050s. However, it would be the highest (22%) yield increase under RCP4.5 scenario with CO_2 fertilization for Alemaya genotype if planted with same density. The yield of both lentil genotypes would increase if planted with plant spacing of 20 cm and 30 cm between rows. The study appreciates other studies to be conducted on other lentil genotypes to enhance the prodcution of lentil in the upcoming century.

Keywords: Climate projection; genotype, lentil; planting date; plant density; row spacing; yield.

1. INTRODUCTION

Lentil (*Lens culinaris* Medikus) is a self-pollinating diploid (2n= 14 chromosomes) annual crop and belongs to the genus *Lens* of the Vicieae tribe in the Leguminosae (Fabaceae) family, commonly known as the legume family. It originated in the Near East and rapidly spread to Egypt, central and southern Europe, the Mediterranean basin, Ethiopia, Afghanistan, India and Pakistan, China and later to the New World, including Latin America and North America [1]. It is now cultivated in most subtropical and also in the northern hemisphere, including Canada and Pacific northwest regions.

Ethiopia is considered as a center of diversity for lentil and currently lentil is an important pulse crop [2-4]. This makes Ethiopia one of the major lentil-producing countries in Africa [5] and is listed in the top ten countries in the world [6]. Lentil is grown as a source of protein (23-24%) [7] for human consumption and also a rich source of minerals and vitamins for human nutrition and the straw is valuable for animal feed. It is a potential export and cash crop that has the highest price in domestic and international markets compared to all other food leguminous crops and cereals [8]. The crop is generally grown in rotation with cereals to break cereal disease cycles and to fix atmospheric nitrogen, thus reducing the demand and cost for nitrogen fertilizers for other cereal crops production.

The average yield of lentil in Ethiopia is not greater than 800 kg ha-1 [6]. This is mainly due to the changing climate and its consequences and other array of stresses that lead to crop damage and result in reduction in the yields of lentil [9-12]. On the other hand, the total lentil cultivated area in the world is around 4.6 million hectares producing 4.2 million tons with an average productivity of 1095 kg ha-1 [6]. Armenia is the leading country in lentil average grain yield of 2800 kg ha-1, followed by China and Turkey [6].

Lentil requires a minimum of 350 mm rainfall and a maximum of 550 mm during its growth period or total annual rainfall; in the high rainfall areas, good drainage is essential because waterlogging will have a great negative effect on yields and aggravate disease spread, like wilts and root rots. Drought and severe or prolonged hot weather, especially during podding and grain filling period, can also cause loss in yields through pod cracking. Lentil is among the important cool-season food legumes in Ethiopia and is mainly cultivated between 1700 and 2400 meter above sea level where the mean annual rainfall ranges from 700 to 2000 mm [13]. Seeds will germinate at temperatures above freezing but would be best within the range of 18-21℃; temperatures above 27℃ are harmful or deliterious; and optimum temperatures for growth and optimum yields are around 24℃. Lentil is grown in sandy loam soils, alluvial, black cotton soils, or in much heavier soils. Lentil does best in soil with pH ranges of 6.0 - 8.0 and will not tolerate waterlogging, flooding, or soils with high salinity. It is less damaged by drought than by waterlogging.

So far little has been done to address the impact of climate change, which enables farmers to solve their problem via adaptations at farm-level, especifically on lentil in Ethiopia; since lentil is dominantly produced by smallholder farmers based on their indigenous knowledge as reported by Ethiopian Export Promotes Agency [14]. Furthermore, low productivity per unit area and low grain quality (small seeded, undesired color, low plumpness) were typical features of the Ethiopian lentil [9,11]. Overall, little is known about how climate change may affect the country's agriculture, especially lentil production and productivity. Therefore, the specific objective of this study was to identify the best adaptation measure for lentil production under projected climatic conditions.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was carried out at Debre Zeit Agricultural Research Center (Bishoftu area), central highlands of Ethiopia, during 2009-2010 season. According to the Ministry of Agriculture (MOA) [15], the area is characterized under sub-moist, mountain and plateau, tepid to cool climate based on the growing season, temperature and altitude of the area. The research site is located at 8.73°N latitude and 38.98°E longitudes with an elevation ranging from 1931- 2097 metres above sea level (m.a.s.l.).

The study area receives an average annual rainfall of 777 mm and average annual maximum and minimum temperatures of 26.81 and 10.95 °C, respectively, based on the climate data analyses of 1980-2012 periods [16]. Again, the study area receives bimodal pattern of rainfall with "*Belg*" or the short rain season, which is quite small to support crop production, usually occurs during the period from the second week of March to the second or third week of May. The long-term rainy season "*Kiremt"* extends from the second week of June to the last week of September [17].

2.2 Treatments, Experimental Materials and Design

Two lentil genotypes, namely Alemaya X FLIP 88-41L-02-AK-14 and Alemaya were collected from Debre Zeit Agricultural Research Center (AZARC). This was due the fact that in the study area, these genotypes are locally well-known and widely grown by the local farmers and DZARC as a local check was used with other lentil genotypes of National Variety Trial/evaluating new breeding lines/genotypes of lentil. Sowing was performed during late June to mid-July 2009-2010. The treayments were arranged in a randomized complete block design (RCBD) with four replications. The unit plot size was 3.2 m^2 (4 m x 0.8 m) with spacing of 20 cm between rows and about 2 cm between plants for both genotypes. Planting was done via calculating at seed rate of 800 seeds/plot, meaning, 200 seeds per row. Harvesting were done from 2 central rows of each plot, 1.6 m^2. All other recommended agronomic practices were kept normal and uniform to ensure normal plant growth and development. Seed yield of the selected rows were recorded and then converted into yield per hectare (kg ha^{-1}).

Whereas, long-term meteorological data, i.e. thirty-four years of rainfall, maximum and minimum temperature baseline data were collected from the National Meteorological Agency of Ethiopia for the same period. Projected climate data: rainfall, maximum and minimum temperatures were downscaled from MarkSim web version for IPCC AR5 data (CMIP5). (The website is available at the link: (http://gisweb.ciat.cgiar.org/MarkSimGCM/)[18]). In the processes of downscaling, six climate models, namely BCC-CSM1-1; CSIRO-Mk3-6-0; HadGEM2-ES; MIROC-ESM; MIROC-ESM-CHEM; MIROC5 under two representative concentration pathways (RCPs): RCP4.5 and RCP8.5, were employed (Table 1). The models selected are highly applicable for African climate studies [18-19]. Thus, changes in climate over Bishoftu over the determined period from 2030's to 2050's were recorded as monthly temperature changes (in°C) and monthly precipitation changes (in %) from the base period of 1980-2012.

Table 1. Representative Concentration Pathways (RCP) CO_2 in ppm

CO_2	Concentration(ppm)
Baseline	360
RCP4.5 near century	423
RCP4.5 mid century	487
RCP8.5 near century	432
RCP8.5 mid century	541

Source: Adopted from Meinshausen [21]

2.3 Description of Crop Model: DSSAT

For this particular study, the CROPGRO model, which is embedded within the Decision Support System for Agrotechnology Transfer (DSSAT) version 4.5 [19] was used to simulate daily phenological development and growth and yields of lentil in response to environmental and management factors. The model employed soil data, crop management data and daily meteorological data as an input to simulate daily leaf area index (LAI) and vegetation status parameters, biomass production and final yield. The daily meteorological data included solar radiation, rainfall, maximum and minimum air temperatures. The major soil data included soil type, slope and drainage characteristics, and physico-chemical properties or parameters for each soil layer, such as saturated soil water content, lower drained limit, upper drained limit, initial soil water content, relative root distribution, soil pH, bulk density and soil organic matter. The crop management data included genotype, planting date, plant density, irrigation and fertilizer (application dates and rates). The model calculated the phenological and morphological development of the crop using temperature, day length and genetic characteristics. The water and nitrogen balance sub-models, likewise, provide feedback that influenced developmental and growth processes in the model [20]. Genotypic differences in growth, development and yield of crop cultivars are affected through genetic coefficients (cultivar-specific parameters) that are inputs to the model. However, model calibration has been done prior to any simulation, which was undertaken by comparing the simulated values of development and growth characteristics of each crop with their corresponding observed values, and by calculating statistical parameters of an agreement between simulated and observed values. Finally, the formula used to calculate the yield as influenced by climate change was:

$$\Delta Y = \frac{Y_s - Y_b}{Y_b} \times 100$$

Where; ∆Y=change of yield, Ys= simulated yield, Yb= baseline yield for Impact

3. RESULTS AND DISCUSSION

3.1 Projected Climate over the Central Highlands of Ethiopia

3.1.1 Mean monthly rainfall at bishoftu

The research findings indicated that the average monthly rainfall in the upcoming periods under both climate scenarios (RCP4.5 and RCP8.5) would be much higher than the baseline rainfall condition (Fig. 1). However, during the *Belg* and *Bega* seasons of Ethiopia, the deviation not as such as could be seen from the figure. Rather, it was more or less equivalent with the baseline amount of rainfall.

3.1.2 Mean monthly rainfall during lentil growing season

It has been recommended that lentil planting time in Ethiopia should be late June to mid-July in both mid and high altitude areas as per the Ethiopian Export Promotes Agency [14]. Lentil is considered as drought-resistant crop that can tolerate low annual rainfall distribution even in the range of 280-300 mm [22]. It performs best in areas having annual rainfall ranging from 700-2000 mm in Ethiopia [23,11]. However, high humidity with excessive rainfall during the growing season promotes vegetative growth, which later prevents good yield and seed quality. This current study revealed that excess amount of rainfall would be expected in the coming periods: by 2030's and 2050's under RCP4.5 and

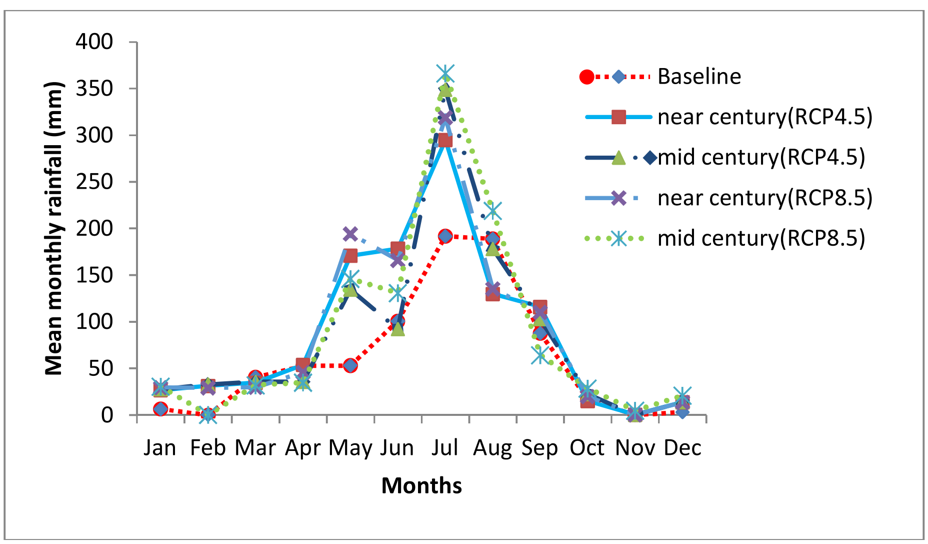

Fig. 1. Baseline and projected mean monthly rainfall feature at Bishoftu

RCP8.5 scenarios during lentil growing seasons compared to the baseline amount of rainfall (Fig. 2). This implies that the production of lentil in the area could suffer damage from waterlogging and other consequences of excess rainfall unless otherwise any kind of adaptation measures is taken in advance. Moreover, the investigation revealed that the highest average rainfall during lentil growing season would be be in July, in both time slices under both RCPs considered in this study. This result goes in line with Vizy and Cook [24] and Yemenu [25] who reported a projected increase in heavy precipitation over East Africa with high certainty in the SREX.

3.1.3 Mean monthly maximum and minimum temperatures at bishoftu

Furthermore, the study investigated that the mean monthly maximum and minimum temperatures over Bishoftu, central highlands of Ethiopia, would increase, and is far above the monthly temperature baseline values. However, the increase varied with the time slices and with RCPs considered (Fig. 3 and Fig. 4). Hadgu et al. [26] reported similar findings in northern Ethiopia. Ethiopia would face warming in the upcoming periods. Without adequate adaptation measures, most of the regions of Ethiopia is likely to be deleteriously affected by rising temperatures due to increasing rates of evaporation and transpiration [27,18,28]. Some of these changes are already being experienced across the region; others are predicted to happen in the near future [29].

Also, it has been reported that climate model projections under the SRES A2 and B1 scenarios over Ethiopia show warming in all four seasons across the country, which may cause a high frequency of heat waves as well as high rates of evaporation [30].

3.1.4 Mean monthly maximum and minimum temperature during lentil growing season at Bishoftu

Lentil can grow in different environments from cool temperate to subtropical dry zones [31]. Different types of lentils are now grown in large areas of warm temperate, subtropical and high altitude of the tropics as a cool season crop [32]. Lentil is capable of germinating at a temperature above freezing point but optimum germination occurs at the range of 18-21℃. Temperatures exceeding 27℃ can harm the crop aggressively but optimum temperatures for growth and yields of lentil are around 24℃ (Muehlbauer, 1996). Looking into the results of this present finding (Fig. 5 and Fig. 6), almost in both time slices under both RCPs, the average maximum and minimum temperatures lied above the baseline. The results also showed that there would be be temperature variability over the study site with different months during lentil-growing season. This could, again;have big influences on the production and productivity of lentil in Bishoftu, central highlands of Ethiopia.

The present study implies an increase in temperature stresses in the area during the

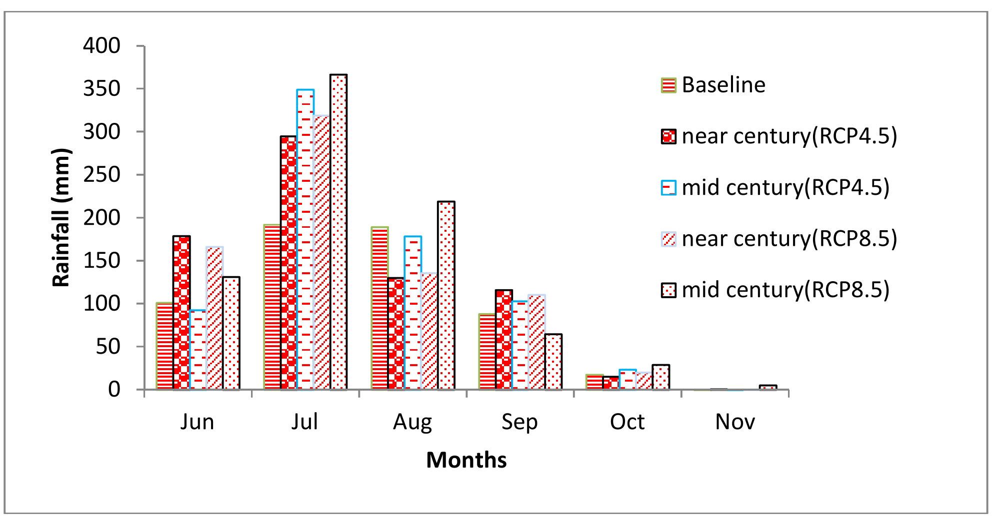

Fig. 2. Baseline and projected mean monthly rainfall feature during lentil growing season at Bishoftu

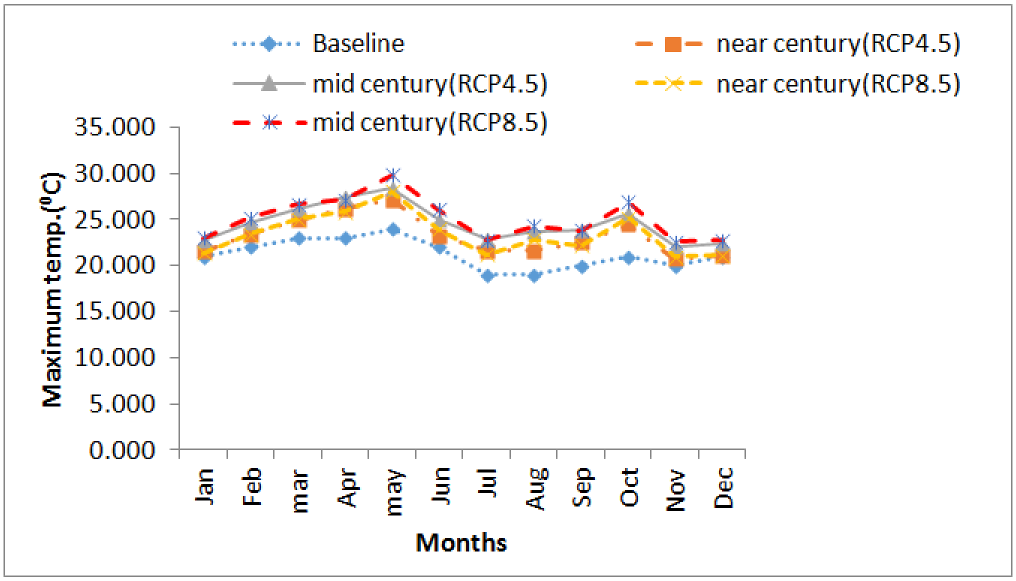

Fig. 3. Baseline and projected monthly maximum temperature pattern at Bishoftu

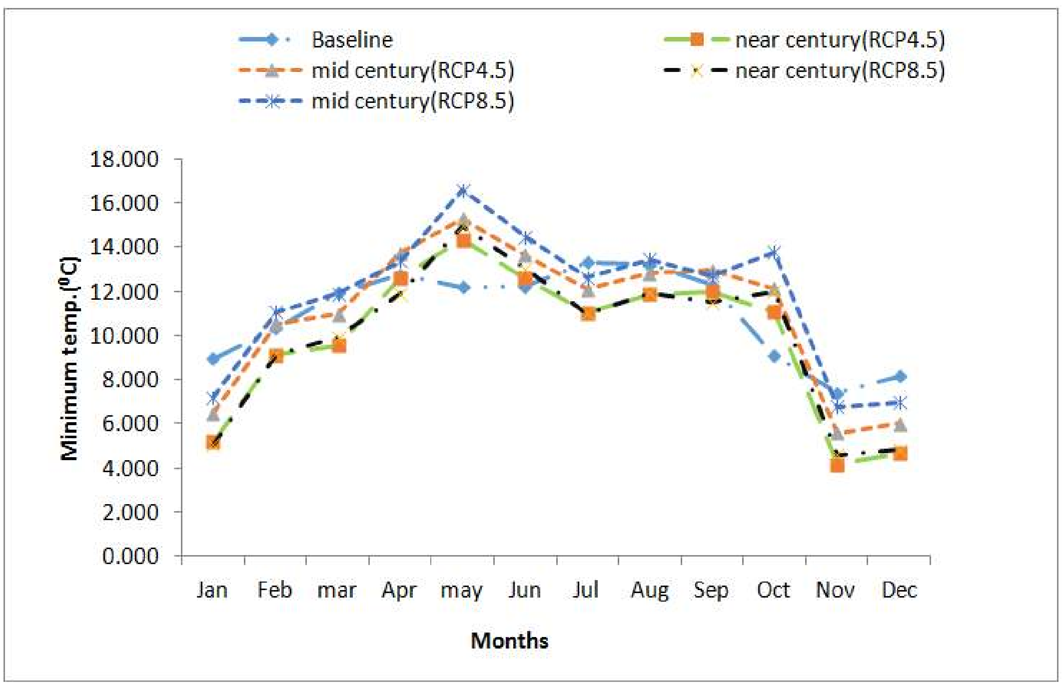

Fig. 4. Baseline and projected monthly minimum temperature pattern at Bishoftu

crop-growing season, which might affect crop production in many aspects. For instance, increased heating leads to greater evaporation and results in surface drying, which, in turn, leads to crop failure. In the long run, this would lead to the impact of long-term dry spells and even leads to drought, thereby resulting in failure of crop production and causes for food insecurity in specific areas and becomes the nationwide problem as well. Additionally, it was investigated that in some months of the year, there would be slight increase in temperature resulting in heat stress that could induce flower abortion and poor seed set of crops.

3.2 Identification of Best Adaptation Measures against the Projected Climate for Lentil Production and Productivity

3.2.1 Sowing date

The effect of sowing date on the yield of two lentil genotypes (Alemaya X FLIP 88-41L-02-AK-14 and Alemaya) for baseline period and future climate simulated with and without CO_2 fertilization is tabulated (Table 1). The result showed that sowing date played a significant role in the yield of thegenotypes Alemaya X FLIP 88-41L-02-AK-14 and Alemaya. Under the future climate (during the 2030s and 2050s) with the RCP4.5 scenario and no CO2 fertilization, the yield of the genotype Alemaya X FLIP 88-41L-02-AK-14 would decrease if planted early in June and at the 3rd decade of July compared to baseline yields (Table 2). However, the yield would increase during all the planting dates that were considered for this study, under both time

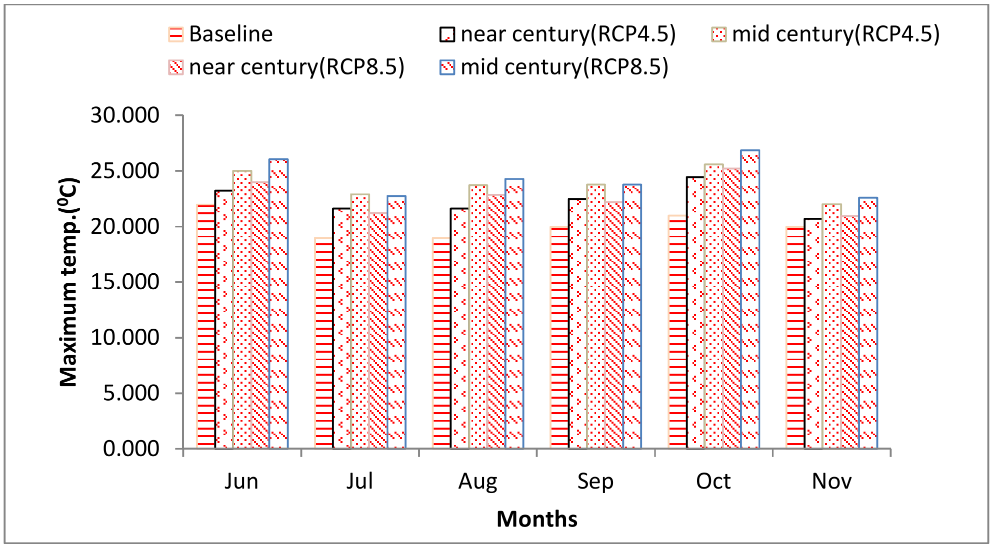

Fig. 5. Baseline and projected monthly maximum temperature pattern during lentil growing season at Bishoftu

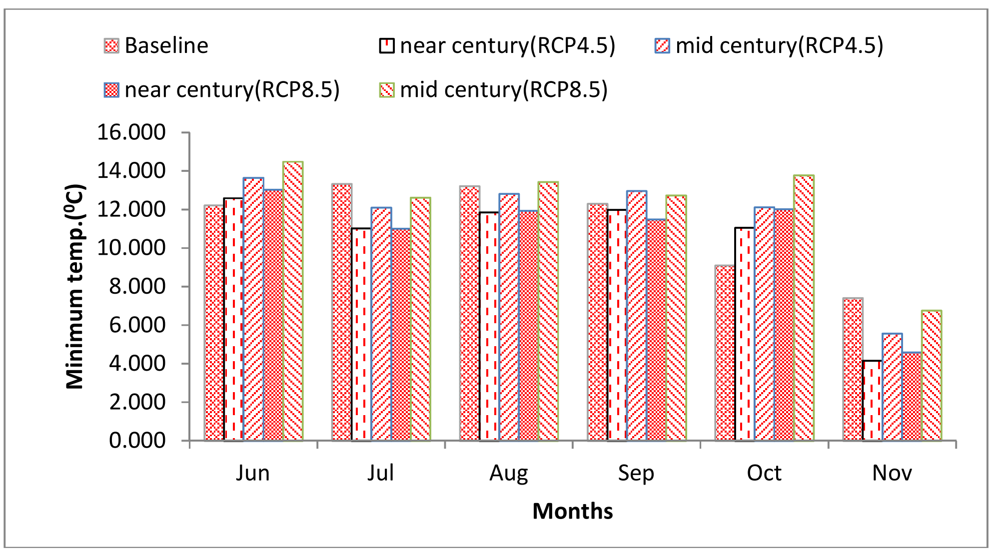

Fig. 6. Baseline and projected monthly minimum temperature pattern during lentil growing season at Bishoftu

slices with both RCPs. The highest yield increase of the genotype Alemaya X FLIP 88-41L-02-AK-14 would be recorded if planted in the 2nd decade of June with CO_2 fertilization during mid century under RCP8.5, accounting for about 26%. This would be followed by 23% when planted in the 1st decade in July under RCP4.5 with CO_2 fertilization. In contrast, low yield of the genotype Alemaya X FLIP 88-41L02-AK-14 would be recorded by 2050s without CO_2 fertilization under RCP4.5; the reduction would be by 11.5% if planted early in June (Table 1).

Comparing with the baseline period, planting date would have also an effect on the yield of the genotype Alemaya as well (Table 2). The highest (19.7%) grain yield increase for this genotype would be expected under RCP8.5 scenario with CO_2 fertilization by the mid century. Whereas, the highest yield decrement would be under RCP4.5 scenario without CO_2 fertilization by the near century, when planted early inJune. In general, the current research result is in agreement with that of the findings of Cuculeanu et al. [33] and Masanganise et al. [34] who reported that change in sowing date could be used as effective adaptation option to climate change impacts in different crops.

3.2.2 Seed rate

The recommended seeding rate for conventional production of lentil in western Canada is 130 plants m^{-2} [35]. Lentil seeding rate studies performed in other countries; however, consistently recommend higher densities than 130 plants m^{-2} to optimize yield or to suppress weeds. In a study conducted in Italy, the optimal plant density for lentil, when using mechanical weed control, was 177 to 250 plants m^{-2} [36]. The present study alsorevealed that plant density has a big influence on the yields of both lentil genotypes considered in this study. The yield of the genotype Alemaya X FLIP 88-41L-02-AK-14 decreased with the increasing plant density under RCP4.5 scenario without CO2 fertilization by 2030s (Table 3). Moreover, the present study showed high (16%) yield increasefor this genotype would be under RCP8.5 scenario by 2050s if planted with 100 plants m-2. However, for the genotype Alemaya, it would be high (22%) yield increase under RCP4.5 scenario with CO2 fertilization (Table 3).

3.2.3 Row spacing

The effect of row spacing on the yield of genotype Alemaya X FLIP 88-41L-02-AK-14 and Alemaya for baseline period and future climate simulated with and without CO_2 fertilization is depicted (Table 4). The result showed that row spacing showed significant role in the yield of both lentil genotypes. Under the future climate (2030s and 2050s) with the RCP4.5 scenario and CO_2 fertilization, yield of both lentil genotypes would increase if planted with plant spacing of 20 cm for Alemaya X FLIP 88-41L-02-AK-14 genotype and 30 cm for Alemaya genotype. However, the highest (12%) yield increase for the genotype Alemaya X FLIP 88-41L02-AK-14 would be under RCP4.5 scenario with CO_2 fertilization by near century, and for the genotype Alemaya (13%) would be under same scenario, but by mid century.

Table 2. Effect of sowing date on yield changes (%) of Alemaya X FLIP 88-41L-02-AK-14 and Alemaya genotypes, compared to the baseline data, by the 2030s and 2050s under the RCP4.5 and RCP8.5 scenarios simulated with and without CO_2 fertilization at Bishoftu

Sowing date		RCP4.5				RCP8.5			
	Baseline yield (kg ha^{-1})	Without CO_2 fertilization		With CO_2 fertilization		Without CO_2 fertilization		With CO_2 fertilization	
	Alemaya X FLIP 8841L-02-AK-14:	2030s	2050s	2030s	2050s	2030s	2050s	2030s	2050s
01-June	1800	-1.5	-11.5	+6	+12.3	-10.2	-10.8	+23	+20.9
20-June	2356	+4.7	+13	+2	+14.8	-1.6	-6.8	+17	26.84
10-July	2456	+13.4	+1.5	+23	+12.4	+1.6	11.7	+27	+21.7
30-July	1708	-1.6	+6	+14	+2.7	-3.1	-4.6	+13	+14.5
	Alemaya:								
01-June	1958	-9.4	-4.4	+3	+8.7	-1.97	-4.6	+2	+1.5
20-June	2243	+1.3	+2	+12	+4.7	-0.07	+8.1	+13	+2.2
10-July	2301	-1.6	+5	+8	+4.6	6.5	-5.8	+27	+19.7
30-July	2007	-9	-2.7	+11	+5.4	+6.9	-3.5	+1.5	+2.6

[CO_2] for each period and scenario is given on Table 1

Table 3. Effect of plant density on yield changes (%) of Alemaya X FLIP 88-41L-02-AK-14 and Alemaya genotypes, compared to baseline, by the 2030s and 2050s under the RCP4.5 and RCP8.5 scenarios simulated with and without CO_2 fertilization at Bishoftu

Baseline yield (kg ha^{-1})		RCP4.5				RCP8.5			
		Without CO_2 fertilization		With CO_2 fertilization		Without CO_2 fertilization		With CO_2 fertilization	
Seed rate (m^{-2})	Alemaya X FLIP 8841L-02-AK-14:	2030s	2050s	2030s	2050s	2030s	2050s	2030s	2050s
100-plants	2461	+1	+2	+4	+6	-3	-4	+16	+2
150-plants	2189	+3	+3	+4	+4	+2	+1.4	+12	+14
200-plants	2415	-1.2	+2	+5	-2.5	+4	+1.1	+7	+4
250-plants	2010	-1.6	-6	+8	+4	+5	-5.8	+27	+7
	Alemaya:								
100-plants	1640	+2	-1.6	+11	+22	+17	+3	+3	+4
150-plants	2450	+1	+9	+2	+3	+1.4	-2	+6	+8
200-plants	2312	+6	-6	+6	+4	-1.1	+7	+2	+3
250-plants	1567	-3	+6	-1	+3	-5	+6	-7	+5

[CO_2] for each period and scenario is given on Table 1

Table 4. Effect of row spacing on yield changes (%) of Alemaya X FLIP 88-41L-02-AK-14 and Alemaya genotypes, compared to baseline, by the 2030s and 2050s under the RCP4.5 and RCP8.5 scenarios simulated with and without CO_2 fertilization at Bishoftu

Row spacing (cm)	Baseline yield (kg ha^{-1})	RCP4.5				RCP8.5			
		Without CO_2 fertilization		With CO_2 fertilization		Without CO_2 fertilization		With CO_2 fertilization	
	Alemaya X FLIP 88-41L-02-AK-14:	2030s	2050s	2030s	2050s	2030s	2050s	2030s	2050s
10	2453	-6	+2	-4	-1	+2	+6	+18	+2
20	2345	+3	-13	+12	+9	-5	+2	+1	+2
30	1987	+3	-11	+4	+4	-1.7	+2.1	+2	+2
40	1567	-3	+5	-9	-7	-3	-4	+7	+2
	Alemaya:								
10	1678	+3	+6	-1	+2	+1.7	+2.3	+9	+4
20	2598	-6	+1.5	+6	+13	-9	-2	+1	+5
30	2123	-3	+4	+12	+2	-4	+1	-1	+12
40	1567	+6.7	-7	-1	-4	+1	+3	+3	+11

[CO_2] for each period and scenario is given on Table 1

4. CONCLUSION

The study showed that there would be much extreme events of climate change in the study area. Thus, we need to work more on our farming communities, particularly those who grow lentils in Bishoftu area. Amongst what to do, determination of best adaptation measure and creating awareness regarding about the future climate to the grass root level should critical issue. This is to ensure climate resilient green economy in central highlands of Ethiopia. The study also appreciates other studies to be conducted on other lentil genotypes to enhance the prodcution of lentil in the upcoming century.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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