Journal of Agriculture and Environment for International Development - JAEID 2016, 110 (2): 377-395
DOI: 10.12895/jaeid.20162.510

Modeling climate change impact on chickpea production and adaptation options in the semi-arid North-Eastern Ethiopia

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Submitted on 2016, 17 July; accepted on 2016, 17 December. Section: Research Paper

Abstract: The semi-arid north-eastern Ethiopia region is characterized by low and variable rainfall. Terminal drought stress is the major constraint for chickpea production in this region. Climate change has also become one of important up growing issue as a consequence of the increasing concentration of greenhouse gases in the atmosphere. In the present study, we used CROPGRO-Chickpea model to evaluate climate change impact on chickpea production and adaptation options at two different locations. Based on the simulation result, chickpea grain yield is predicted to increase under the projected climate changes (temperature, rainfall and CO_2) in 2030s and 2050s time periods for all climate scenarios. Accordingly, mean chickpea grain yield is predicted to increase at Sirinka by about 20% and 34% in 2030s and 2050s, respectively under all climate scenarios. On the other hand, the increase in mean chickpea grain yield at Chefa is predicted to be 12% and 22% across the respective time periods. Cultivars changes are predicted to significantly affect chickpea grain yield across the different time periods. Based on the result, short duration cultivar is found to increase grain yield at Sirinka by about 11%, 10% and 11% in the baseline, 2030s and 2050s, respectively, but decrease grain yield at Chefa by about 9%, 4% and 5%. On the other hand, long duration cultivar is predicted to decrease grain yield at Sirinka by about 6%, 9% and 11%, but increase grain yield at Chefa by about 1%, 2% and 4% across the respective time periods as compared to the standard (control) cultivar. The result also indicated that supplemental irrigation is found to increase grain yield of chickpea at Sirinka by about 48%, 46% and 46% in the baseline, 2030s and 2050s time periods, respectively whereas the increase in grain yield at Chefa is predicted to be 17%, 16% and 18% across the respective time periods. Therefore, grain yield of chickpea in semi-arid environments can be significantly increased using suitable cultivars and supplemental irrigation in the present and future climate conditions.

Keywords: climate change, CROPGRO-Model, drought, semi-arid

Introduction

The agriculture sector is the key to livelihoods in Ethiopia as it accounts for 52% of national income and 80% of employment (Hanjra *et al.,* 2009). Ethiopia's rapidly growing population relies on a fragile natural resource base for livelihood security conditioned by timely and adequate rainfall. Smallholders produce more than 90% of total agricultural output and cultivate close to 95% of the cropped land. Land and water resources are highly underdeveloped, as most smallholders lack access to irrigation, and agriculture remains largely rainfed and highly dependent on rainfall (Hanjra *et al.,* 2009). Coupled with lack of land, variability and unpredictability in rainfall persists, which is a key reason for Ethiopia now ranking as one of the countries at most 'extreme risk' from the effects of climate change. About 50% of Ethiopia's land area is arid or semi-arid, and largely represent the lowland areas of the country. In such areas, the coefficient of inter-annual rainfall variability around the mean is as high as 30% (Bewket, 2007). Current scientific evidence also suggests that global climate change will lead to greater rainfall variability which will further impede the Ethiopian's farming sector (World Bank, 2011). Ferede *et al.* (2013) in a recent article also discussed the importance of specific agroecological conditions in different parts of Ethiopia in influencing how climate change will impact crop productivity in the country. In recent decades, the Ethiopia's farming systems have been subject to critical rainfall variability leading to fluctuations in production and, in some years, severe food crises in parts of the country (World Bank, 2011). The ultimate purpose of climate change risk assessment is to identify adaptation strategies for attaining sustainable development in a specific region (Luo *et al.*, 2009). Such adaptation strategies include improved varieties, shifts in recommended planting dates and rates, novel cropping sequences, change in the number of fallow years required for soil-water recharge in rainfed systems, and introduction of alternative or new crops (White *et al.*, 2011).

Chickpea (*Cicer arietinum* L.) is the third most important pulse crop in the world after dry beans (*Phaselous vulgaris* L.) and dry peas (*Pisum sativum*) (Parthasarathy *et al.*, 2010). It is cultivated on 11.5 million hectare with a production of 10 million tons with the productivity of 863 kg ha^{-1} (FAOSTAT, 2012). Although chickpea is a crop of temperate region, its cultivation is gradually spreading to sub-tropical and tropical regions. Chickpea is cultivated on large scale in arid and semiarid environment. About 90% of the world's chickpea is grown under rainfed conditions where the crop grows and matures on a progressively depleting soil moisture profile and experiences terminal drought, a condition in which grain yield of chickpea is low (Kumar and Aboo, 2001). Chickpea is a highly nutritious grain legume crop. It is valued for its beneficial effect of increasing productivity of succeeding crops in rotation and, hence, raising sustainability and profitability of production systems (Soltani and Sinclair, 2012).

Despite huge importance of the crop for human diet and land improvement, yield of the crop is still below the expected level in Ethiopia (Kassie *et al.,* 2009). A number of factors which could be abiotic and/ or biotic limit the productivity of chickpea.

Among abiotic constraints, drought is the most important factor limiting chickpea production (Singh *et al.*, 2008). Occurrence of drought is a common phenomenon in arid and semi-arid areas of north-eastern Ethiopia. The seasonal patterns of light, temperature, water, air humidity and carbon dioxide concentration (CO_2) are the main determinants for crop growth and consequently for crop productivity. Agricultural crop production is certainly going to be affected under future climate change. However, because of regional differences in both natural and anthropogenic factors that control plant responses, the intensity of climate impacts on crop yields can vary depending upon location, climate change scenarios and crop (Tubiello *et al.*, 2002). More frequent and intense precipitation events, elevated temperatures, drought, and other types of damaging weather are all expected to impact crop yield and quality (Hatfield *et al.*, 2010). Chickpea cultivation is solely dependent on soil moisture reserve where planting is made late during the recession of the main rainy season to escape the water-logging condition. The flowering and pod setting stages of chickpea appear to be the most sensitive stages to water stress (Nayyar *et al.,* 2006). Imtiaz *et al. (*2011) reported that chickpea will be benefited by rises in temperature to a certain extent and the yield is forecasted to be increased by about 45–47% under doubled levels of CO_2. Singh *et al.* (2013) also reported that climate change will increase grain yield of chickpea in 2050s by about 17% to 25% at the cooler sites but decrease yield by 7% to 16% at the warmer sites as compared to the yields under baseline climate of the sites.

The generations of new data through conventional agronomic research methods are not sufficient to meet the increasing needs. Conventional agronomic experiments are conducted at particular points in time and space, making results site and season specific, time consuming and expensive. Agricultural systems are complex, and understanding this complexity requires systematic research. Field experimentation can only be used to investigate a very limited number of variables under a few site specific conditions. The impact of weather on crop growth, development and yield can be best represented by crop-weather models, which facilitate the study of the relationship among weather, climate and crop yield. Crop modeling has proven to be a powerful tool to extrapolate experimental data obtained under very specific weather and soil conditions to other cropping environments, and so, to shorten the experimental process needed to establish better cropping strategies, using long term multi-year weather simulations and statistical analysis.

In view of the increasing population and anticipated climate change, production must continue to increase to meet the current and future demand for food in the country. This may be possible through improved crop management options that to suite to the target region. However, there is no published work on impact of supplemental irrigation chickpea productivity especially in the semi-arid areas of north-eastern Ethiopia. Therefore, we evaluated the impact of supplemental irrigation and sowing dates on productivity of different maturity duration of chickpea cultivars using CROPGRO-Chickpea model in semi-arid areas of north-eastern Ethiopia where chickpea is an important crop.

Materials and Methods

The study sites

The study was carried out in two sites (Sirinka and Chefa) found in North-Eastern Ethiopia. Sirinka is located at an altitude of 1850 meter above sea level with geographic coordinates of 11.45.00 N latitude and 39. 36. 00 E longitude. The mean annual air temperature is 26 ^{0}C and mean annual rainfall is 741 mm. Chefa is located at an altitude of 1450 m above sea level with geographic coordinates of 10. 43. 12. N latitude and 39. 49. 48 E longitude. The mean annual air temperature ranges from 28.5 ^{0}C and mean annual rainfall is 983 mm. The north-eastern Ethiopia is characterized by rugged topography with undulating hills and valley bottoms. Black soil (Verisols) is the dominant soil type and gray soil (Vertic Inceptisols) is of secondary importance. The region receives bimodal rainfalls that include: the small rainfall season from February to April/May (locally known as *Belg*) and the main rainfall season from June to September (locally known as *Kiremt*). Rainfall in the region is highly variable and erratic. As a result, terminal drought stress is a major constraint for most crops. Major Field crops include: sorghum, chickpea, haricot bean, field pea and lentil. Mixed cropping (crops and livestock) is the major production system. Mono cropping and sole cropping are dominant; however, crop rotation (cereals with pulse crops) and intercropping are also practiced at some extent. Almost all field crops are grown under rainfed condition during the main season (June to September); however, some crops are also grown during the small rainy season (February to April/May). Chickpea is mainly grown in the post rainy season of the main season as sole crop.

The CROPGRO-Model

We used the CROPGRO-Chickpea model to study the impact of crop management options on chickpea productivity. The model is part of the suite of crop models available in DSSAT software (Hoogenboom *et al.*, 2010). The major components of the model are vegetative and reproductive development, carbon balance, water balance and nitrogen balance (Singh and Virmani, 1996). It simulates chickpea growth and development using a daily time step from sowing to maturity and ultimately predicts yield. Genotypic differences in growth, development and yield of crop cultivars are affected through genetic coefficients (cultivar-specific parameters) that are inputs to the model. The physiological processes that are simulated describe the crop response to major weather factors, including temperature, precipitation and solar radiation and include the effect of soil characteristics on water availability for crop growth. Soil water balance is a function of rainfall, irrigation, transpiration, soil evaporation, runoff from the soil surface and drainage from the bottom of the soil profile. The soil water balance submodel used in CROPGRO-chickpea model found in the DSSAT program is described in detail by Ritchie (1998).The volumetric soil water content varies among each soil layer between a lower limit (LL- corresponding to the permanent wilting point) and a saturated upper limit (SAT- corresponding to the saturation point). If the water content is above the drained upper limit (DUL- corresponding to field capacity), then the water drains to the next soil layer. Daily surface runoff of water was calculated using the USDA Soil Conservation Service (SCS) curve number technique. The runoff curve number (CN) was supplied as input, which ranges from 0 (no runoff) to 100 (all runoff) based on soil type, land cover and surface residue applied. In the model, high temperature influences growth and development and reduces allocation of assimilates to the reproductive organs through decreased pod set and seed growth rate. Increased CO_2 concentration in the atmosphere increases crop growth through increased leaf-level photosynthesis. Increased CO_2 concentration also reduces transpiration from the crop canopy via an empirical relationship between canopy conductance and CO_2 concentration. Thus the model has the potential to simulate crop growth and development of chickpea cultivars under climate change conditions, such as high air temperatures, variability in rainfall and increased CO_2 concentrations in the atmosphere that ultimately result in final crop yields at maturity.. The CROPGRO-chickpea model was updated and modified mostly the crop parameters in the species file of the model. These changes were based on the research findings of Wang *et al.* (2006) and Devasirvatham *et al.* (2012a).

Model calibration and evaluation procedures

The CROPGRO-Chickpea model requires genetic coefficients that describe the growth and development characteristics for each individual cultivar. In this study, the genetic coefficients of the cultivar *Kutaye* were estimated by model iterations until a close match between simulated and observed phenology, growth and yield were obtained. These coefficients were used in the subsequent evaluation and application. The calibration of CROPGRO-Chickpea model was carried out using sowing date experiment conducted in 2014 at two different sites. Before attempting to calibrate the crop genetic coefficients, the soil parameters that most determine the simulation of soil moisture were calibrated. Soil moisture was measured up to 60 cm depth, hence the volumetric soil water was calibrated for the conditions of soil layers of 0 -

30 cm and 30-60 cm by adjusting two of the water holding characteristics (lower limit and drainage upper limit) in order to match the simulated values to the observed values for the purpose of making the simulations more specific to the conditions of the field. The CROPGRO-Chickpea model was calibrated using the cultivar developmental stages (days to flowering and days to physiological maturity), crop growth measurement parameters (biomass, LAI, grain yield and yield components) that showed the best performance against the measured data in the field experiments. Accordingly, the genetic coefficients describing the growth and yield of the test variety were determined.The model evaluation stage involves the confirmation that the calibrated model closely represents the real situation. The procedure consists of a comparison of simulated output and observed data. The CROPGRO-chickpea model was evaluated by the data from the field experiments and data sets of 2005 and 2006 obtained from chickpea variety trials.

Climate data for the target sites

Simulation of climate change adaptation required projected climate data to modify the observed weather data of the study sites. In order to investigate adaptation options for rainfed chickpea in the present and future climate conditions (2020-2049) and (2040-2069), daily weather variables such as rainfall, maximum temperature, minimum temperature and solar radiation were obtained from the WorldClim baseline climate data (1980-2009) , and the 17 CMIP5 GCM outputs run under RCP2.6, RCP 4.5, RCP6 and RCP 8.5 for 2030s and 2050s time slice were downloaded for the target sites from CIAT's climate change portal (http:/ccafs-climate.org) and downscaled to the target sites using MarkismGCM. For any location, MarkSim makes use of a climate record. A climate record contains the latitude, longitude and elevation of the location, and monthly values of rainfall, daily average temperature and daily average diurnal temperature variation. It also includes the temporal phase angle, that is, the degree by which the climate record is "rotated" in date. This rotation is done to eliminate timing differences in climate events, such as the seasons in the northern and southern hemispheres, so that analysis can be done on standardized climate data. The climate record is rotated to a standard date, using the 12-point Fast Fourier transform, on the basis of the first phase angle calculated using both rainfall and temperature (Jones *et al.,* 2003). In MarkSim, almost all operations are done in rotated date space. The climate database WorldClim V1.3 is used to interpolate the climate at the required point. WorldClim may be taken to be representative of current climatic conditions (most of the data cover the period 1980–2009). It uses historical weather data from a number of databases. WorldClim uses thin plate smoothing with a fixed lapse rate employing the program ANUSPLIN. Bicubic interpolation is used over a kernel of the nearest sixteen GCM cells on a 1 x 1 degree grid of GCM differentials. These are calculated from polynomials fitted to each GCM result which are used to return the values for any year or RCP regime. The ensemble (of 17 GCMs in this case) is calculated directly from the polynomial coefficients for each GCM. The estimated GCM differential values are added to the rotated record. This is an example of unintelligent downscaling (Wilby *et al.,* 2009) to the monthly climate values. MarkSim then uses stochastic downscaling to simulate the daily weather sequences.

Climate scenarios

The four climate scenarios that include RCP2.6, RCP4.5, RCP6 and RCP8.5 (IPCC, 2013) for near term (2020-2049) and mid- term (2040-2069) were used to analyze the climate change at both locations. However, only the two scenarios (RCP4.5 and RCP8.5 in 2030s and 2050s) with the baseline scenario (1980-2009) were considered to simulate crop management scenarios. Accordingly, 360 ppm CO_2 for the baseline climate, 423 ppm, 423 ppm, 419 ppm and 432 ppm CO_2 for RCP 2.6, RCP4.5, RCP 6 and RCP 8.5 in 2030s, respectively and 443 ppm, 499 ppm, 493 ppm and 571 ppm CO_2 for RCP2.6, RCP 4.5, RCP6 and RCP 8.5 in 2050s, respectively were considered (IPCC, 2013) in this study. RCP's are greenhouse gas concentration trajectories adopted by the IPCC for its fifth assessment. RCP2.6 is the most ambitious pathway. It sees emissions peak early, then fall due to active removal of atmospheric carbon dioxide. This pathway is also referred to as RCP3PD (representing the mid-century peak radiative forcing of 3 Wm^{-2} followed by a decline. It has no counterpart in IPCC AR4. Scenario RCP4.5 is also similar to the lowest-emission scenario (B1) assessed in the IPCC AR4. Scenario RCP6.0 pathway stabilizes total radiative forcing shortly after 2100 by the application of a range of technologies and strategies for reducing greenhouse gas emissions. On the other hand, RCP8.5 scenario is the highest emission scenario. It arises from little effort to reduce emissions and represents a failure to curb warming by 2100. It is similar to the highest-emission scenario (A1FI) in the IPCC Fourth Assessment Report (AR4).

Crop management scenarios

The possibilities for achieving more benefit of chickpea grain yield were tested using supplemental irrigation and cultivars of different maturity groups. The supplemental irrigation here after designated as (SI) was applied two times at the critical growth stages of the crop (flowering and pod initiation). For the first and second application equal amount of 65 mm of water each was applied at Sirinka during the flowering and pod initiation stage of the crop whereas for the first and second application 75 mm of water each was applied at Chefa. It was assumed that the supplemental irrigation water was applied when the available soil moisture in the crop rooting depth reaches 60% of its field capacity. Hence, the amount of water applied was the amount that replenishes the soil water content in the rooting depth back to its field capacity level. To evaluate grain yield of cultivars of different maturity duration, virtual cultivars incorporating various plant traits were developed from the baseline cultivar (*Kutaye*) calibrated for the north-eastern Ethiopian conditions which represents farmers' preference for the *Desi* type of chickpea cultivars grown at both sites. Three maturity durations of chickpea cultivars were considered - baseline (no change), 10% shorter maturity and 10% longer maturity. To make the crop maturity short, genetic coefficients determining emergence to 50% flowering (EM-FL), flowering to beginning seed growth (FL-SD) and beginning seed growth to physiological maturity (SD-PM) were decreased by 10% each. To make the crop maturity long, these coefficients were increased by 10% each.

Statistical analysis

All the multi-year simulation output data of crop grain yields were analyzed using analysis of variance (ANOVA) and the randomized complete block design (RCBD). Simulation years were considered as replications (blocks), as the chickpea yield in one year under a given treatment was not affected by another year (prior year carry-over of soil water was not simulated). Also, the simulation years had unpredictable weather characteristics; therefore, a formal randomization of simulation years (blocks) was not needed. The analysis was done using SAS V 9.1.2 (SAS, 2003) software and means were separated using least significance test (LSD). Descriptive statistics such as percentile characteristics were used to describe adaptation strategies.

Results and Discussion

Calibration and evaluation of the CROPGRO-Chickpea model

Using the sowing date experimental data sets the cultivar coefficients were adjusted until flowering and physiological maturity dates, leaf area index, grain and above ground biomass yields were simulated within 10% of the measured values. The RMSE between observed and predicted values in the calibration phase of the experiment for flowering, maturity, LAI, grain yield (kg/ha), above ground biomass yield (kg/ha) and pod yield were 3, 1, 0.46, 429, 551 and 286, respectively. The d-index values for these parameters were 0.92, 0.95, 0.97, 0.97 and 0.96 and 0.88, respectively. The result indicated that the cultivar specific parameters within the model were reasonably adjusted. The CROPGRO-Chickpea model was also evaluated by comparing the simulated data with the observed field data. Model evaluation against measured values showed that the model was able to predict the number of days to flowering and days to maturity very close to the observed results. The average RMSE for all the treatments between the observed and the predicted days to flowering and days to maturity were results was 1.54 and 2.78, respectively. The RMSE values for grain weight (kg ha^{-1}), above ground biomass weight (kg ha^{-1}), pod weight (kg ha^{-1}) and LAI were 347, 949, 269 and 0.56, respectively. The d-index values for the respective parameters were 0.94, 0.84, 0.97 and 0.82, respectively. The result generally indicated that there was a close agreement between the simulated and observed values of the growth parameters.

Projected Climate Changes in the Study Areas

Projected rainfall

Based on analysis of projected future climate changes in 2030s (2021-2049) and 2050s (2041-2069), monthly rainfall total is predicted to increase in the semi-arid environments of north-eastern Ethiopia for all the climate scenarios as compared to the simulated value for the baseline scenario (1980-2009). Accordingly, mean annual rainfall is predicted to increase at Sirinka by about 14.4%, 11.4%, 15% and 13.8% in 2030s and by about 15.8%, 14.7%, 13.6% and 13.4% in 2050s under RCP2.6, RCP4.5, RCP6 and RCP8.5 scenarios respectively. Similarly, mean annual rainfall total is predicted to increase at Chefa by about 4.4%, 1.7%, 0.3% and 1.9% in 2030s and by about 4.4%, 14%, 1.5% and 16.1% in 2050s under the respective scenarios. Mean monthly rainfall total is also predicted to increase at both sites in the chickpea growing season of 2030s and 2050s. The increase in rainfall total in future climate is predicted to benefit the crop for its normal growth and development. In line with this result, Wing *et al.* (2008) reported that a small increase in annual precipitation is expected both in the wet and dry seasons over Ethiopia. Christensen *et al.* (2007) also reported that with the SRES A1B emission scenario, mean annual rainfall is likely to increase around 7% in tropical and eastern Africa in 2080-2099 time periods. According to IPCC (2001) report, east Africa will experience warmer temperatures and a 5-20% increased rainfall amount from December-February and 5-10% decreased rainfall from June-August by 2050.

Projected air temperature

Based on result of future climate projection, mean annual maximum and minimum temperatures are predicted to increase in 2030s and 2050s time periods at both sites for RCP2.6, RCP4.5, RCP6 and RCP8.5 scenarios as compared to the simulated value for the baseline scenario. In general, the projected mean annual maximum air temperature is predicted to increase at Sirinka in the range of 1.1 to 1.5 in 2030s and in the range of 1.3 to 2.5 in 2050s whereas mean annual minimum air temperature is predicted to increase in the range of 1.3 to 1.7 in 2030s and in the range of 1.5 to 2.8 in 2050s. The projected mean annual maximum air temperature is predicted to increase at Chefa in the range of 1.2 to 1.6 ^{O}C in 2030s and in the range of 1.2 to 2.5 in 2050s whereas annual minimum air temperature is predicted to increase in the range of 1.3 ^{o}C to 1.7 in 2030s and in the range of 1.3 to 2.7 in 2050s. The prediction result also showed that both annual maximum and minimum temperatures will increase at both sites during the chickpea growing season of 2030s and 2050s for all the climate scenarios. In agreement with this result, Wing *et al.*, (2008) reported for the IPCC emission scenarios, the mean annual temperature will increase in the range of 0.9 -1.1 °C by 2030, in the range of 1.7 - 2.1 °C in the 2050s and in the range of 2.7-3.4 °C in 2080s over Ethiopia compared to the 1961-1990 normal. Climate scenarios for Africa based on results from several general circulation models using data collected by the Intergovernmental Panel on Climate Change also indicated that future warming across Africa will be ranged from 0.2°C per decade for low scenario to more than 0.5°C per decade for high scenario. This warming is greatest over the interior of semi-arid margins of the Sahara and Central Southern Africa (Aschalew, 2007). There are high levels of confidence in projecting continuing temperature increase over the country. For instance, Yimer *et al.* (2009) and Ayalew *et al.* (2012) reported that Ethiopia would experience further warming by the years 2020 and 2050 in all seasons. The increase in future temperature particularly during the chickpea growing season is predicted to affect chickpea production. For instance, increased heating may lead to greater evaporation followed by drying of the surface. If it is not offset by adequate moisture, it could lead to increase the intensity and duration of drought and it may lead to poor crop harvest. Moreover, an increase in mean temperature will also affect irrigation water requirement and could decrease yield either due to moisture stress and/or limitation of area to be irrigated.

Effect of projected temperature, rainfall and CO_2 on phenology of chickpea

According to the result, reductions in days to flowering and days to maturity of chickpea are predicted at both sites in 2030s and 2050s time periods under all climate scenarios as compared to the simulated value under the baseline climate. The highest significant reductions in days to flowering and days to maturity of chickpea are predicted for scenario RCP8.5 in 2030s and 2050s. The highest significant reduction in days to flowering and days to maturity of chickpea for RCP8.5 scenario in 2030s and 2050s could be associated more to its highest temperature. The simulated result in general indicated that days to flowering and days to maturity of chickpea are predicted to decrease in 2030s and 2050s time periods. The reduction in days to flowering and maturity of chickpea could be attributed more to the increase in future temperature that could alter the crop growth and development stages. Higher temperature could speed up growth and development stages and lead to reduction in crop life cycle. The reduction in days to flowering and days to maturity of the crop could reduce lead to reduction in grain yield. In agreement with this result, Hong *et al* (2011) reported that among the three climate scenarios (A1B, A2 and B1) the scenario that reduced days to plant maturity the most was scenario A2, which is associated with its higher temperature. As the crop growth cycle is strongly related to temperature, the duration of a crop life cycle is conditioned by the daily temperatures absorbed by the plant. Therefore, an increase in future temperature could lead to speed up growth and development of crops that ultimately reduce the duration between sowing and harvesting. As a result, grain yield accumulation could fall with the shortening of a crop life cycle (IFPRI, 2011). However, based on the results of this current study, the increase in maximum and minimum temperature by 2030s and 2050s time periods in north-eastern Ethiopia could not affect chickpea grain yield negatively but shorten the crop life cycle due to enhancement of development rate.

Effect of projected temperature, rainfall and CO_2 on grain of chickpea

Based on the result, chickpea grain yield is predicted to increase in 2030s and 2050s time periods under the projected climate changes (temperature, rainfall and CO_2) for all the climate scenarios. Based on the result, chickpea grain yield is predicted to increase at Sirinka by about 20% in 2030s and by about 34% in 2050s

Table 1 - Mean simulated days to flowering (DF) and day to maturity (DM) of chickpea at Sirinka and Chefa in the baseline, 2030s and 2050s under different climate scenarios

Time periods	Climate change scenarios	DF		DM	
		Sirinka	Chefa	Sirinka	Chefa
1961-1990	baseline	52.7a	54.2a	109a	124a
2030	RCP2.6	51.2b	52.3b	104.6b	117.5b
	RCP4.5	50.9b	52.3b	104.2b	117.6b
	RCP6	51.2b	52.3b	104.8b	117.5b
	RCP8.5	50.7c	52c	103.6c	115.1c
2050	RCP2.6	50.9b	52.3b	103.9bc	117.b
	RCP4.5	50.5c	52.c	103d	115.2c
	RCP6	50.5c	51.9c	103.3cd	115.3c
	RCP8.5	50d	51d	101.8e	113d

Note: Means followed with the same letter (s) in each column are not significantly different at 5% probability level predicted to increase at Sirinka by about 20% in 2030s and by about 34% in 2050s considering all the climate scenarios. However, the increase in grain yield at Chefa is predicted to be about 12% in 2030s and 22% in the 2050s. Across the scenarios, chickpea grain yield is predicted to increase in the ranges of 17%-26% at Sirinka and in the range of 11% -15% at Chefa in 2030. Grain yield is also predicted to further increase in the range of 19%-50% at Sirinka and in the range of 14%-31% at Chefa in 2050. In general, the effect of projected climate change on chickpea grain yield is predicted to be positive at both sites despite the increase in both maximum and minimum temperature. The increase in grain yield of chickpea under the projected climate change condition could be associated more to the increase in rainfall in future climate condition. The increase in rainfall could improve soil moisture condition that leads to increase chickpea productivity. Other possible reason could be drought escaping (earliness) mechanism of the chickpea variety from terminal drought. The increase CO_2 concentration in future climate condition could also benefit the chickpea crop as carbon dioxide is a substrate in photosynthesis. There is also evidence that showed water use efficiency is greater under high CO_2 concentration as transpiration is reduced as a result of reduced stomatal conductance (Fleisher *et al.,* 2008). Wani *et al* (2005) also reported that the increase in CO_2 concentration will have beneficial effects on crops, especially the legumes (C_3 species) by increasing the photosynthesis rate. Imtiaz *et al. (*2011) also reported that chickpea will be benefited by rises in temperature to a certain extent and the yield is forecasted to increase by about 45–47% under doubled levels of CO_2. Singh *et al.* (2013) also reported that climate change will increase grain yield of chickpea in 2050s by about 17% to 25% at the cooler sites but decrease yield by 7% to 16% at the warmer sites as compared to the yields under baseline climate of the sites.

Table 2 - Effect of projected climate changes (temperature, rainfall and CO_2) on grain yield (GY) of Chickpea at Sirinka and Chefa as compared to simulated values under the baseline scenario

Time period	Scenarios	CO_2 (ppm)	GY (kg ha-1)	
			Sirinka	Chefa
1980-2009	Baseline	360	1961b	3404c
2030s (2020-2049)	RCP2.6	419	2291ba	3787bc
	RCP4.5	423	2320ba	3822bc
	RCP6	423	2324ba	3773bc
	RCP8.5	432	2476ba	3899bac
2050s (2040-2069)	RCP2.6	443	2335ba	3888bac
	RCP4.5	499	2632ba	4235ba
	RCP6	493	2607ba	4085ba
	RCP8.5	571	2935a	4444a

Note: Means followed with the same letter (s) in each column are not significantly different at 5% probability level

Effect of cultivars on grain yield of chickpea in the baseline, 2030s and 2050s under RCP4.5 and RCP8.5 scenarios

The effect of different maturity group of cultivars on chickpea grain yield was evaluated in the baseline, 2030s and 2050s under RCP4.5 and RCP8.5 scenarios. According to the result, short duration cultivar is predicted to increase grain yield at Sirinka by about 11% under the baseline scenario, by about 10% and 9% in 2030s and by about 12% and 10% in 2050s under RCP4.5 and RCP8.5 scenarios, respectively. However, short duration cultivar is predicted to decrease grain yield at Chefa by about 9% under the baseline scenario, by about 4% in 2030s, and by about 3% and 6% in 2050s under RCP4.5 and RCP8.5 scenarios, respectively. Long duration cultivar is predicted to decrease grain yield at Sirinka by about 6% under the baseline scenario, by about 8% and 10% in 2030s, and by about 11% in 2050s under RCP4.5 and RCP8.5 scenarios, respectively. On the other hand, long duration cultivar is predicted to increase grain yield at Chefa by about 1% under the baseline scenario, by about 2% in 2030s and by about 4% in 2050s under RCP4.5 and RCP8.5 scenarios, respectively.

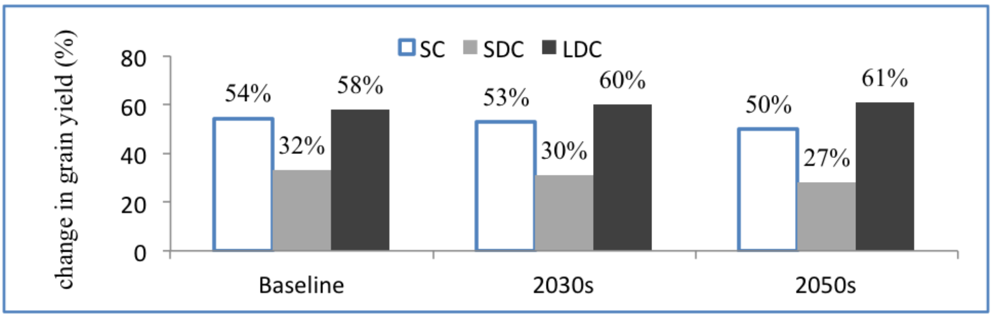
The simulation result showed that short duration cultivars are more productive in low moisture areas where rainfall is generally low and erratic. Short duration cultivars can escape the problem of terminal drought stress that often occurs at flowering, pod setting and grain filling stages of the crop. Therefore, developing faster-maturing chickpea varieties is required. Such strategy would seem promising where climate change is expected to shorten growing seasons. On the other hand, long duration and medium (standard) duration cultivars are more productive in high temperature areas. High temperature affects most crops development and growth stages by shortening their life cycle. Long duration cultivars are found to have greater productivity in such high temperature area. Such cultivars can maintain the adverse effect of high temperature on their growth and development. In general, long duration cultivars are more suitable in areas where moisture regimes exhibit little change but high temperature is a major constraint for crop production. Thus, longer maturing varieties are required to maintain the length of time for total crop development as temperatures warm. Changes in genotype have been suggested to be the most promising adaptation option in the world. For instance, Tubiello *et al.* (2002) found that switching to longer-maturing winter wheat varieties at sites with plentiful moisture fully offsets the 15% projected yield losses under climate change. According to the report of Luo *et al.* (2009) earlier maturity cultivars may be needed to match future drier conditions. Boote *et al.* (2011) also suggested that genetic improvement of crops for greater tolerance to elevated temperatures and drought improved responsiveness to rising CO_2 and the development of new agronomic technologies to adapt crops to the current adverse climates and climate change. The study therefore conclude that the present and future crop breeding program should focus on developing both short and long duration varieties that could increase grain yield of chickpea in semi-arid environments of northeast Ethiopia.

Effect of supplemental irrigation on grain yield of chickpea in the baseline, 2030s and 2050s under RCP4.5 and RCP8.5 scenarios

The effect of supplemental irrigation on chickpea grain yield was evaluated at both sites in the baseline, 2030s and 2050s time periods under RCP4.5 and RCP8.5 scenarios. According to the result, supplemental irrigation is predicted to increase mean chickpea grain yield at Sirinka by about 48% under the baseline scenario, by about 47% and 45% in 2030s and by about 46% and 45% in 2050s under RCP4.5 and RCP8.5 scenarios, respectively. On the other hand, supplemental irrigation is predicted to increase mean chickpea grain yield at Chefa by about 17% under the baseline scenario, by about 15% and 17% in 2030s and by about 19% and 18% in 2050s under RCP4.5 and RCP8.5 scenarios, respectively. The response to supplemental irrigation is predicted to vary among cultivars. Under supplemental irrigation condition, higher grain yield is predicted for the long duration cultivar as compared to the short duration cultivar. This indicates that whenever irrigation water is available long duration cultivars are more advantageous in terms of increasing chickpea productivity under the semi-arid environments of north-eastern Ethiopia.

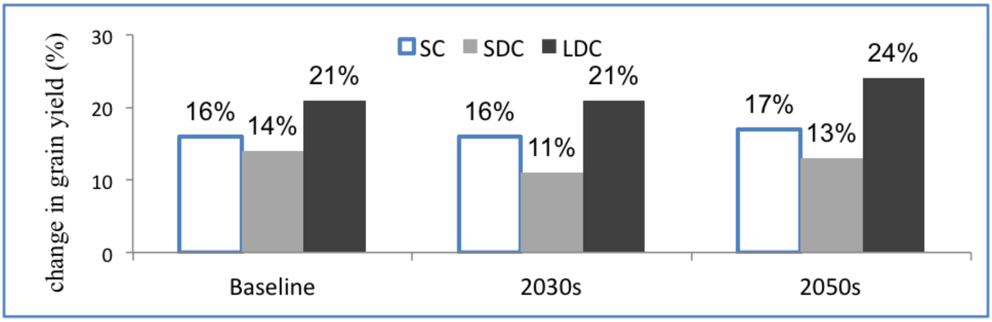
The simulation result in general indicated that although chickpea can be grown under limited moisture conditions, the crop requires adequate supply of moisture for its proper growth and development. However, in many semi-arid tropical environments, water is a very scarce resource and the amount of water available for supplemental irrigation may be generally low. However, water harvesting is

Figure 1 - Percent change in cultivars grain yield under supplemental irrigation as compared to rainfed yield at Sirinka



Note: SC, SDC and LDC stand for standard, short duration and long duration cultivars, respectively

Figure 2 - Percent change in cultivars grain yield under supplemental irrigation condition as compared to rainfed yield at Sirinka.



Note: SC, SDC and LDC stand for standard, short duration and long duration cultivars, respectively

becoming a popular strategy in many semi-arid areas. This will improve the amount of water required for supplemental irrigation. In addition, an efficient application of water is very crucial as it can contribute significantly to reducing water losses and increasing water use efficiency. The result of the current study indicated that better responses from supplemental irrigation could be achieved when irrigation water is applied at the critical crop growth stages (flowering, grain and pod setting). As rainfall in many semi-arid environments is generally unpredictable and highly variable, supplemental irrigation will be the most viable option to increase chickpea productivity.

Conclusion

The crop simulation analysis in this particular study has shown that potential rainfed chickpea yield in north-eastern Ethiopia would be substantially increased under all projected climate changes. The projected increase in concentration of atmospheric CO_2 is predicted to positively affect grain yield of chickpea. However, grain yield of chickpea could further increase using crop management and genetic options.

The result showed that short duration cultivar is more productive in low rainfall area where terminal drought stress is major constraint for crop production. Short duration cultivars can escape the effect of terminal drought stress by completing their life cycle before the occurrence of the drought. Therefore, developing faster-maturing chickpea varieties for areas with short and variably rainfall could be required in the present and future climate conditions. Such varieties would seem promising where climate change is expected to shorten growing seasons. On the other hand, long duration and medium (standard) duration cultivars are more suitable in areas where high temperature is major crop production constraint. Such varieties can maintain the adverse effect of high temperature on growth and development. Thus, longer maturing varieties would be required to maintain the length of time for total crop development as temperatures warm.

Although chickpea can be grown under limited moisture conditions, the crop requires adequate supply of moisture for its proper growth and development. Water is a very scarce resource in the semi-arid tropical environments of north-eastern Ethiopia and the amount of water available for supplemental irrigation may be generally low. However, nowadays water harvesting is becoming a popular strategy in Ethiopia so that supplemental irrigation could be possible in many areas. In addition, an efficient application of water is very critical as it can contribute significantly to reducing water losses and increasing water use efficiency.

References

Aschalew A., 2007. Climate change detection and attribution in tropical Africa. Research Report.Addis Ababa University. Addis Ababa.

Ayalew D., Tesfaye, K., Mamo, G.,Yitaferu, B. and Bayu, W., 2012.Variability of rainfall and its current trend in Amhara region, Ethiopia. Afr J Agric Res 7(10):1475–1486

Bewket W., 2007. Rainfall variability and the need for water security in Ethiopia. In the Nile Waters and Ethiopia: Mainstreaming the Nile Issue into the Media, Academia and Research Institutions. Workshop Proceedings, Addis Ababa: Flamingo Printing Press PLC.

Boote K. J., Ibrahim A., Lafitte R., McCulley R., Messina C., Murray S., Specht J., Taylor S., Westgate M., Glasener K., Bijl C., and Giese J., 2011. Position statement on crop adaptation to climate change. Crop Sci. 51, 2337-2343.

Christensen J., Hewitson B., Busuioc A., Chen A., Gao X., Held I., Jones R., Koli R., Kwon W., Laprise R., Rueda V., Mearns L., Menéndez C., Räisänen J., Rinke A., Sarr A., and Whetton P., 2007. Regional climate projections. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., and H.L. Miller, Eds., Cambridge University Press, Cambridge, 847-940.

Devasirvatham V., Gaur P.M., Mallikarjuna N., Tokachichu R.N., Trethowan R.M., and Tan D.K.Y., 2012a. Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. Functional Plant Biol. 39(12), 1009-1018.

FAOSTAT., 2012. Food and Agriculture Organization of the United Nations 2012.

FAO Production Year Book. Available at http://apps.fao.org. Rome, FAO (accessed 15:01:13).

Ferede T., Ayenew A.B., and Hanjra M.A., 2013. Agroecology Matters: Impacts of Climate Change on Agriculture and its Implications for Food Security in Ethiopia (Chapter 3, pp. 71-112). In: Global Food Security: Emerging Issues and Economic Implications. Editor: Munir A. Hanjra, Nova Science Publishers, New York, USA.

Fleisher D.H., Timlin D.J. and Reddy V.R., 2008. Elevated carbon dioxide and water stress effects on potato canopy gas exchange, water use and productivity. *Agric Forest Meteorol* 148, 1109–1122.

Hanjra M.A., Tadele F., and Debel Gemechu Gutta., 2009. Pathways to breaking the poverty trap in Ethiopia: Investments in agricultural water, education, and markets. Agricultural Water Management 96: 1596–1604.

Hatfield J.L., Boote K.J., Kimball B.A., Ziska L.H., Izaurralde R.C., Ort D., Thomson A.M., and Wolfe D., 2010. Climate Impacts on Agriculture: Implications for Crop Production. Agronomy journal, 103(2): p. 351-370.

Hong W., Yong H., Budong Q., Brian M., Herb C., Tom M., Grant M., Robert Z., Con C., Ron, D., Reynald L., Kelsey B., Tingting L., Xiaobo Q., Gerrit H., Jeffrey W., and Tony, H., 2011. Impact of Climate Change on Wheat Production for Ethanol in SouthernSaskatchewan, Canada.World Renewable Energy Congress 2011, Sweden: 8-13 May 2011, Sweden.

Hoogenboom G., Jones J.W., Wilkens P., Porter C.H., Boote K.J., Hunt L.A., Singh U., Lizaso J.L., White J.W., Uryasev O., Royce F.S., Ogoshi R., Gijsman A.J., and Tsuji G.Y., 2010. Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.5 [CD-ROM]. University of Hawaii, Honolulu, Hawaii.

Internation Food Policy Research Institure (IFPRI). 2011. Simulating the Impact of Climate Change and Adaptation Strategies on Farm productivity and Income: A Bioeconomic Analysis. West and Centeral Africa Office.IFPRI Discustion paper 01095, June, 2011.

Imtiaz M., Malhotra R.S., and Yadav S.S., 2011. Genetic adjustment to changing climates: Chickpea. In: Yadav SS, Redden RJ, Hatfield JL, Lotze-Campen H, Hall AE, eds. *Crop Adaptation to Climate Change*. Oxford: Wiley-Blackwell. p 251–268.

IPCC., 2001. Synthesis report. Cambridge University Press. Cambridge.

IPCC., 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kassie M., Shiferaw B., Asfaw S., Abate T., Muricho G., Ferede S., Eshetu M., and Asefa K., 2009. Current situation and future outlooks of the chickpea Sub-sector in Ethiopia. ICRISAT (Nairobi) and EIAR (Debre Zeit).

Kumar J., and Abbo S., 2001. Genetics of flowering time in chickpea and its bearing on productivity in semiarid environments. Advances in Agronomy, 72: p. 107-138.

Luo Q., Bellotti W., Williams M., and Wang E., 2009. Adaptation to climate change of wheat growing in South Australia: Analysis of management and breeding strategies. Agriculture, Ecosystems & Environment, 129(1–3): p. 261-267.

Nayyar H., Singh S., Kaur S., Kumar S., and Upadhyaya H., 2006. Differential sensetivity of macrocarpa and macrocarpa types of chickpea (cicer arietinum) to water stress accociation of contrasting stress response with oxidative inujury. J.integr. plant Biol. 48:1318-1329.

Parthasarathy P., Birthal P.S., Bhagvatula S., and Bantilan M.C.S., 2010. Chickpea and Pigeonpea Economies in Asia: Facts, Trends and Outlook. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India, PP. 76.

Ritchie J., Singh U., Godwin D., and Bowen W., 1998. Cereal growth, development and yield. In: Tsuji, G., Hoogenboom, G., Thornton, P. (Eds.), Understanding Options for Agricultural Production. Kluwer Academic Publishers, Dordrecht, pp. 79–98.

SAS. 2003. SAS Version 9. 1.2 © 2002-2003. SAS Institute, Inc., Cary, NC.

Schmidt G.A., 2006. Present day atmospheric simulations using GISS ModelE: Comparison to in-situ, satellite and reanalysis data. J. Climate 19, 153-192.

Singh P., and Virmani S.M., 1996. Modelling growth and yield of chickpea (Cicer arietinum L.). Field Crop Res. 46, 41-59.

Singh R., Sharma P., Varshney R.K., Sharma S., and Singh N., 2008. Chickpea improvement: role of wild species and genetic markers. Biotechnology and Genetic Engineering Reviews 25: 267-314.

Singh P, Nedumarana S., Boote K., Gaura P., Srinivasa K., and Bantilana M., 2013. Climate change impacts and potential benefits of drought and heat tolerance in chickpea in South Asia and East Africa

Soltani A., and Sinclair T., 2012. Optimizing chickpea phenology to available water under current and future climates. European Journal of Agronomy, 38(0): p. 22-31.

Song Z., Qiao F., and Song Y., 2012. Response of the equatorial basin-wide SST to wave mixing in a climate model: An amendment to tropical bias, J. Geophys. Res., 117, C00J26.

Tubiello F. N., Rosenzweig C., Goldberg R. A., Jagtap S., and Jones J.W., 2002. Effects of climate change on US crop production: simulation results using two different GCM scenarios. Part I: Wheat, potato, maize, and citrus. Clim. Res. 20:259-270.

Wang J., Gan Y.T., Clarke F., and McDonald C.L., 2006. Response of chickpea yield to high temperature stress during reproductive development. Crop Sci. 46, 2171–2178.

Wani S., Singh P., Dwivedi R., Navalgund R., and Ramakrishna A., 2005. Biophysical indicators of agro-ecosystem services and methods for monitoring the impacts of NRM technologies at different scale. In *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts* (eds Shiferaw, B., Freemen, H. A. and Swinton, S. M.), CAB International, Wallingford, UK, pp. 97–123.

White J. W., Hoogenboom G., Kimball B.A., and Wall G.W., 2011. Methodologies for simulating impacts of climate change on crop production. Field Crops Research, 124(3): p.357-368.

Wilby R.L., Troni J., Biot Y., Tedd L., Hewitson B.C., Smith D.M., Sutton R.T., 2009. A review of climate risk information for adaptation and development planning. Int. J. Climatol. 29, 1193–1215.

Wing H., Gabriel B., and Ashbindu S., 2008. Trends and Spatial distribution of annual and seasonal rainfall in Ethiopia. International Journal of Climatology, Vol. 28, Issue 13, pp: 1723- 1734.

World Bank., 2011. Climate-Smart Agriculture: Increased Productivity and Food Security, Enhanced Resilience and Reduced Carbon Emissions for Sustainable Development, Opportunities and Challenges for a Converging Agenda: Country Examples. World Bank, Washington, D.C.

Yimer G., Jonoski A. and Griensven A.V., 2009. Hydrological response of a catchment to climate change in the upper Beles river basin, upper Blue Nile, Ethiopia. Nile Basin Water Eng Sci Mag 2:49–59