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Management options for rainfed chickpea (*Cicer arietinum* L.) in northeast Ethiopia under climate change condition

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A B S T R A C T

Chickpea (*Cicer arietinum* L.) is one of the important cool season food legumes in the semi-arid north-eastern Ethiopia. Climate change is projected to alter the growing conditions of chickpea in this region and there would be substantial reduction in grain yield of the crop due to drought. The overall objectives of the study were to identify crop management and genetic options that could increase rain-fed chickpea productivity. For this, a simulation study has been conducted using CROPGRO-model in two sites (Sirinka and Chefa) found in the semi-arid north-eastern Ethiopia. Change in planting date and cultivars having different maturity have been tested for their effectiveness to increase chickpea productivity. According to the prediction result, short duration cultivar is found to increase grain yield at Sirinka by about 11%, 10% and 11% in the baseline, 2030 s and 2050 s, respectively whereas long duration cultivar is found to decrease grain yield by about 6%, 9% and 11% as compared to the standard cultivar (control). On the other hand, short duration cultivar is found to decrease grain yield at Chefa by about 9%, 4% and 5% whereas long duration cultivar is found to increase grain yield by about 1%, 2% and 4% across the respective time periods. Early sowing (SSD – 20 days) is found to significantly increase grain yield of short duration cultivar at Sirinka by about 48%, 48% and 54% and that of long duration cultivar by 31%, 33% and 39% in the baseline, 2030 s and 2050 s, respectively. Early sowing (SSD – 20 days) is also found to increase grain yield of short duration cultivar at Chefa by about 26%, 27% and –1% and that of long duration cultivar by 37%, 32% and –2% across the respective time periods. However, the highest increase in chickpea grain yield can be achieved through combined application of early sowing and suitable cultivars. On the other hand, delayed sowing is found to significantly decrease chickpea grain yield in the semi-arid environments of north-eastern Ethiopia.

1. 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

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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 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).

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 of Asia, Africa, North America and Oceania. 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 Abbo, 2001). Average chickpea yield remains low in the major chickpea producing countries due mainly to inadequate water supply (Soltani and Sinclair, 2012). 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. Thus, 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). A parallel study of the same authors (Mohammed et al., 2016a,b) has been carried out to understand the interactions between different aspects of climate change on chickpea in the semi-arid north-eastern Ethiopia. Based on the result, projected climate change will have some positive implication on chickpea productivity. Increase in yield of rainfed chickpea under climate change has also been reported by Koocheki et al. (2006) and by Gholipoor and Soltani (2009).

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, 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). Sowing date is the most frequently varied option (White et al., 2011), which will surely be adjusted to increase temperature. Under warmer future climates, earlier sowing is likely to require cultivars with different phenological development than currently used (Soltani and Sinclair, 2012).

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 agronomic and genetic improvement of the crop to suite the target environments considering both the current and future climates. However, there is no published work on genetic and management aspects of chickpea to increase its productivity especially in the semi-arid areas of north-eastern Ethiopia. Therefore, we evaluated various agronomic and genetic options (sowing dates and cultivars of different maturity groups) using CROPGRO-Chickpea model under the present and projected climate change condition in semi-arid areas of north-eastern Ethiopia where chickpea is an important crop.

2. Materials and methods

2.1. 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 air temperature ranges from 21 to 32 °C and mean annual rainfall is 876 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 air temperature ranges from 21 to 36 °C and mean annual rainfall is 850 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 or stress is a major constraint for most crops. Major Field crops are sorghum, chickpea, haricot bean, field pea and lentil. Mixed cropping (crops and livestock) is the major production system in the area. Mono cropping and sole cropping are dominant in the area; however, crop rotation (cereals with pulse crops) and intercropping are also practiced at some extent. Almost all field crops are grown under rainfed condition in the main rainy season (June to September); however, some crops are grown in the small rainy season (February to April/May). Chickpea is mainly grown in the post rainy season of the main season as sole crop on residual soil moisture.

2.2. Experimental procedures

Experimental data for the calibration and evaluation of the crop model were generated from sowing date experiment conducted in 2014 main season at two sites (Sirinka and Chefa) found in North Eastern Ethiopia. In addition, phenological and yield data sets of 2005 and 2006 obtained from chickpea variety trial experiment were used for model evaluation. An improved and well adapted *desi*-type chickpea variety named '*Kutaye*' was used as a test crop. The land was prepared conventionally using oxen drawn local plow called *Maresha*. Di-ammonium phosphate fertilizer (18% N and 46% P_2O_5) was applied in broadcasted at a rate of 50 kg/ha at the time of sowing. Weed, insect and disease protections were done according to the recommendations for the crop.

2.3. The DSSAT model

DSSAT model (Decision Support System for Agrotechnology Transfer) is one of the most widely used modeling systems across the world. It was initially developed under the auspices of the International Benchmark Sites Network for Agrotechnology Transfer (Hoogenboom, 2003). Currently, the DSSAT shell is able to incorporate models of 28 different crops, including several cereal grains, grain legumes, and root crops (Hoogenboom, 2003). The models are process-oriented and are designed to work independent of location, season, crop cultivar, and management system. The models simulate the effects of weather, soil water, genotype, and soil and crop nitrogen dynamics on crop growth and yield (Jones et al., 2003). DSSAT and its crop simulation models have been used for a wide range of applications, including on-farm and precision management to regional impact assessments of the impact of climate change and variability. As a software package integrating the effects of soil, crop phenotype, weather and management options, DSSAT allows users to ask "what if" questions and simulate results by conducting, in minutes on a desktop computer, experiments which would consume a significant part of an agronomist's career.

2.4. The CROPGRO-model

We used the CROPGRO-Chickpea model to study the impact of crop management options on chickpea productivity. The chickpea 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 (∗.SPE) of the model. These changes were based on the research findings of Wang et al. (2006) and Devasirvatham et al. (2012).

2.5. Model inputs

2.5.1. Field management parameters

Crop management information including sowing date, sowing depth, inter and intra row spacing, start of simulation date, cultivar selection and soil type are required for the crop model. For fertilizer management applications, fertilizer type, application time and depth are required. Fertilizers was applied as DAP (Di-ammonium Phosphate) at a rate of 50 kg ha^{-1} containing 9 kg N ha^{-1} and 23 kg ha^{-1} P_2O_5 ha^{-1}. The fertilizer was applied in broadcast during sowing. Two seeds per hill were sown to ensure germination and good stands of the variety and then thinned to one plant 15 days after emergence.

2.5.2. Soil parameters

About 2 weeks before sowing, the soil samples were taken up to 2 m depth from the soil profile at the field sites for the chemical and physical analysis of the soil. Soil physico-chemical parameters determined included, texture, pH, soil organic carbon, total nitrogen, available phosphorous, exchangeable cations, electrical conductivity and bulk density of each layer. Soil parameters required to determine soil water balance dynamics such as drained upper limit (DUL) of soil water content (cm^3/cm^3), lower limit (LL) of soil water content (cm^3/cm^3), saturated (SAT) water content ($cm3/cm^3$), stage 1 soil evaporation coefficient (U, mm), runoff curve number (CN2), whole profile drainage rate coefficients (SWCON) were initially estimated by inputting soil physical properties data such as soil texture (percentage of sand, silt, and clay), soil organic matter content and soil bulk density into a soil file creation utility program of the DSSAT 4.6 software. These estimated characteristics for the soil were further modified to make more specific for the experimental sites. The soils at Sirinka are classified as Eutric Vertisols and have extractable water capacity of 252 mm while the soils at Chefa are black soil and have extractable water capacity of 364 mm. Soil water content at a depth of 0–30 and 30–60 cm soil layers was determined gravimetrically at weekly interval for each treatment plot starting at sowing until physiological maturity. Samples were taken using soil auger and weighed soon after sampling to get the fresh weight and then oven dried at 105 °C to constant weight.

2.5.3. Weather parameters

Daily recorded weather data are required inputs for model calibration and evaluation and must be available from the day of sowing. The standard weather data used by the CROPGRO-Chickpea model were daily values of maximum and minimum air temperature (°C), daily total precipitation (mm) and daily total solar radiation (M J M^{-2} day^{-1}). These meteorological data were taken from the nearest meteorological stations at Sirinka (300 m) and Kombolcha (10 km) weather stations. WeatherMan utility program of DSSAT 4.6 was used to convert the sun shine hours to solar radiation (M J M^{-2} Day^{-1}).

2.5.4. Crop phenological parameters

Ten randomly selected plants from each plot were tagged for observation of developmental stages and monitored at two or three days intervals. The crop phenological parameters recorded were days to emergence, days to first flowering (50%), days to first pod, days to first seed, and days to physiological maturity. Days to emergence was recorded as number of days from date of sowing to the time when 50% of the seeds emerged. Days to first flowering was recorded as the number of days from date of sowing to the time when 50% of the plants in a plot produced their first flower. Physiological maturity was recorded as number of days from the date of sowing to the time when 95% of the plants in a plot reached physiological maturity.

2.5.5. Crop growth parameters

Ten plants from each plot were randomly selected and harvested at ground level at approximately ten days interval throughout the growing period starting 15 days after emergence leaving appropriate border rows. Growth measurements on leaf area index (LAI), leaf dry matter (g m^{-2}), stem dry matter (g m^{-2}), specific leaf area (cm^2/g), pod dry matter (g m^{-2}), and above ground biomass yield (kg ha^{-1}) were taken at ten days interval throughout the season. For those measurements on weight bases a sub-sample was taken to dry in an oven for 72 h at 60 °C to a constant weight and their weights were determined using a sensitive balance. Total above ground dry matter at each sampling was obtained by summing up the leaf, stem and pod dry matter. Leaf area was measured using a portable leaf area meter (model CI-202).

2.5.6. Yield components and yield

All plants from the central three rows of each plot were harvested to determine final grain yield after threshing. The number of pods per plant was taken from five randomly selected plants from the sample rows of each plot at harvest. The number of seeds per pod was recorded from ten pods of plants used for pod per plant determination. A sub-sample in each fraction was taken to dry in an oven for 72 h at 60 °C to a constant weight and their weight was determined using a sensitive balance. Hundred seed weight was determined by counting hundred randomly taken dried seeds of each plot using an electronic seed counter and weighing with a digital sensitive balance. Finally, harvest index (HI) was determined as the ratio of grain yield to total above ground biomass yield.

2.6. 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 validation and application. 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 validation 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 that have not been previously used in the calibration stage. The CROPGRO-chickpea model was evaluated by the data from the field experiments which were not used in the model calibration stage and data sets obtained from Sirinka Agricultural Research Center. To evaluate model performance and accuracy in prediction, root mean square Error (RMSE) (Wallach and Goffinet, 1987), Willmot's Index of agreement (d), mean absolute error (MAE), coefficient of determination (R^2) and mean deviation (MD) were computed from observed and simulated variables (leaf area index, total above ground biomass, seed biomass, days to flowering, days to physiological maturity, and grain yield).The result of model calibration and evaluation is reported in other paper by the same authors (Mohammed et al., 2016a,b).

2.7. 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 management 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 2030 s and 2050 s 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. The following global circulation models were used to assess crop management options for chickpea. BCC-CSM 1.1 (Wu, 2012), BCC-CSM 1.1 (m) (Wu, 2012), CSIRO-Mk3.6.0 (Collier, 2011), FIO-ESM (Song et al., 2012), GFDL-CM3 (Donner, 2011), GFDL-ESM2G (Dunne, 2012), GFDL-ESM2 M (Dunne, 2012), GISS-E2-H (Schmidt, 2006), GISS-E2-R (Schmidt et al., 2006), HadGEM2-ES (Collins, 2011), IPSL-CM5A-LR (Dufresne, 2013), IPSL-CM5A-MR (Dufresne, 2013), MIROC-ESM (Watanabe, 2011), MIROC-ESM-CHEM (Watanabe, 2011), MIROC5 (Watanabe, 2010), MRI-CGCM3 (Yukimoto, 2012) and NorESM1-M (Kirkevag et al., 2008).

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 1960–1990). 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 1×1 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.

2.8. The 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 2030 s and 2050 s) with the baseline scenario (1980–2009) were considered to simulate different 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 2030 s, 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 2050 s, respectively were considered (IPCC, 2013) in this study. RCP's are greenhouse gas concentration trajectories adopted by the IPCC for its fifth assessment. These scenarios are briefly described as follows. In RCP2.6 (also known as RCP3PD) Greenhouse Gases (GHGs) concentrations rise in the first half of the century and then decline so that the forcing (extra energy trapped in entire atmosphere) is 2.6 Wm^{-2} in the year 2100. Peak forcing is 3 $W\,m^{-2}$ of the 21st century. This is a rapid mitigation scenario of concentration rise. In RCP4.5 scenario, GHGs concentrations rise with increasing speed until the forcing is 4.5 $W\,m^{-2}$ in the year 2100. This is a moderate emission scenario of concentration rise. In RCP6, GHGs concentrations rise with increasing speed until the forcing (extra energy trapped in entire atmosphere) is 6 $W\,m^{-2}$ in the year 2100. This is a moderately-high scenario of concentration rise. In RCP8.5 GHGs concentrations rise with increasing speed until the forcing is 6 $W\,m^{-2}$ in the year 2100. This is a high scenario of concentration rise.

2.9. Crop management scenarios

The possibilities for achieving more benefit of chickpea grain yield were tested by changing sowing dates as a management adaptations options and cultivars of different maturity groups as genetic options in order to find the most suitable strategies with the changing future climate scenarios. The standard sowing date here after designated as SSD was arbitrarily set as the median sowing date of chickpea in the sowing window in the study region which is 10 September each year. Early sowing dates were then set as (SSD – 10 days) and (SSD – 20 days) whereas delayed sowing dates were set as (SSD + 10 days) and (SSD + 20 days). For each site, the simulation was initiated one month before the actual planting date in order to simulate the soil water balance correctly and this was applied for each sowing date treatment in the experiment. Under normal sowing conditions, the sowing window for chickpea is 1 September to 20 September at both sites. At the time of sowing phosphorus (P) at a rate of 23 kg ha^{-1} was applied as Di-ammonium phosphate. A plant population of 33 plants m^{-2} and row spacing of 30 cm was considered for simulating chickpea growth. At both the sites, the crop was grown rainfed in the model. Simulation of management and genetic options were carried out for the temperature, rainfall, solar radiation and carbon dioxide changes of the 2030 s (2020–2049) and 2050 s (2040–2069) time slices and for the baseline scenario (1980–2009). The crop was considered free from pests and diseases. To simulate crop response to the changes in genetic traits, 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 (Mohammed et al., 2016a,b). For developing these virtual cultivars, three maturity durations of chickpea crop 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. For the longer maturity cultivar, these coefficients were increased by 10% each.

2.10. 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.

3. Results and discussion

3.1. Projected climate changes in the study areas

3.1.1. Projected rainfall in the study area

Based on analysis of projected future climate changes in 2030 s (2021–2049) and 2050 s (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 2030 s and by about 15.8%, 14.7%, 13.6% and 13.4% in 2050 s 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 2030 s and by about 4.4%, 14%, 1.5% and 16.1% in 2050 s under the respective scenarios. Mean monthly rainfall total is also predicted to increase at both sites in the chickpea growing season of 2030 s and 2050 s. 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 Hulme et al. (2001) and 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.

3.1.2. Projected air temperature in the study area

Based on result of future climate projection, mean annual maximum and minimum temperatures are predicted to increase at both sites in 2030 s and 2050 s time periods 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 at Sirinka is predicted to increase in the range of 1.1 °C to 1.5 °C in 2030 s and in the range of 1.3–2.5 °C in 2050 s whereas mean annual minimum air temperature is predicted to increase in the range of 1.3–1.7 °C in 2030 s and in the range of 1.5–2.8 °C in 2050 s. The projected mean annual maximum air temperature at Chefa is predicted to increase in the range of 1.2–1.6 °C in 2030 s and in the range of 1.2–2.5 °C in 2050 s whereas annual minimum air temperature is predicted to increase in the range of 1.3–1.7 °C in 2030 s and in the range of 1.3–2.7 °C in 2050 s. The prediction result also showed that both annual maximum and minimum temperatures will increase at both sites during the chickpea growing season of 2030 s and 2050 s for all the climate scenarios. The highest increase in annual maximum and minimum temperatures in 2030 s and 2050 s time periods are predicted for scenario RCP8.5 whereas the lowest increase are predicted for RCP 2.6 scenario. 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. This could be greatly felt in the lowland areas of the region where temperature is naturally high. In these regions, a slight increase in temperature could result in heat stress that induces flower abortion and poor seed set of crops. Heat stress reduces grain yield of cereal crops through reduced growth duration, low light interception, and reproductive failure (Barnabás et al., 2008). 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. However, based on the results of this current study, we conclude that the increase in maximum and minimum temperature in 2030 s and 2050 s time periods in north-eastern Ethiopia could not affect chickpea grain yield negatively but could shorten the crop life cycle due to enhancement of development rate. 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 2050 s and in the range of 2.7–3.4 °C in 2080 s 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), Conway and Schipper (2011), Setegn et al. (2011), Ayalew et al. (2012) reported that Ethiopia would experience further warming by the years 2020 and 2050 in all seasons.

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

The effects of different maturity group of cultivars on chickpea grain yield were evaluated in the baseline, 2030 s and 2050 s under RCP4.5 and RCP8.5 scenarios. Based on the result, short duration cultivar is predicted to increase grain yield at Sirinka by about 11%, 10% and 11%, but decrease grain yield at Chefa by about 9%, 4% and 5% in the baseline, 2030 s and 2050 s, respectively. On the other hand, long duration cultivar is predicted to decrease chickpea 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. The effects of cultivars changes on chickpea grain yield were also evaluated under individual climate scenarios (baseline, RCP4.5 and RCP8.5 scenarios in 2030 s and 2050 s). 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 2030 s and by about 12% and 10% in 2050 s for 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 2030 s, and by about 3% and 6% in 2050 s for 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 2030 s, and by about 11% in 2050 s 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 2030 s and by about 4% in 2050 s under RCP4.5 and RCP8.5 scenarios, respectively (Fig. 1).

In all simulation, the highest increase in cultivars grain yields are predicted for RCP8.5 scenario in 2030 s and 2050 s time periods. This could be associated more to the highest CO_2 concentration for this scenario as compared to the CO_2 concentration for the rest of the scenarios. Carbon dioxide (CO_2) is one of the most important ingredients in photosynthesis and the increase in its concentration in the atmosphere could lead to increase in yield of crops. However, the increase in CO_2 concentration is more significant for C_3 crops because high photorespiration in these crops reduces photosynthesis rate and finally reduce crops yield. The increase in future rainfall is predicted to improve soil moisture condition for normal crop growth and development that could lead to increase chickpea yield.

According to the simulation result, short duration cultivars are more suitable for Sirinka area and similar agro-ecologies in the baseline, 2030 s and 2050 s. Sirinka area is characterized by low and erratic rainfall and terminal drought is usually the major crop production constraint. Short duration cultivars are predicted to be more suitable in this low rainfall area. Short duration cultivars can escape the terminal drought/stress condition that usually occurs at flowering, pod setting and grain

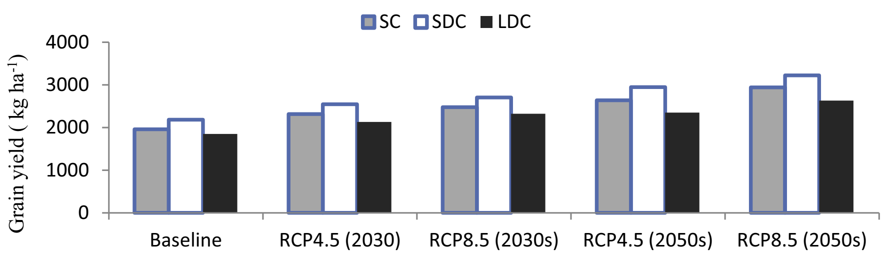

Fig. 1. Comparison of grain yield of cultivars of chickpea at Sirinka in the baseline, 2030 s and 2050 s time periods under RCP4.5 and RCP8.5 climate scenarios.

filling stages of the crop. Therefore, developing faster-maturing chickpea varieties for areas with short and variably rainfall should be a common goal of many crop breeding programs and such a 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 suitable for Chefa and similar agro-ecologies in the baseline, 2030 s and 2050 s as such area is characterized by high temperature. Although this area is under the semi-arid region, low soil moisture is not usually a major problem for crop production because soils have good water holding characteristics. High temperature is usually affects most crops development and growth stages by reducing their life cycle. Long duration cultivars are more promising for such high temperature areas. As a result of the higher temperature effect on the crop growth and development stages, short duration cultivars could be more affected as compared to the medium (standard) and the long duration cultivars. However, long duration cultivars can maintain such adverse effect of high temperature on their growth and development. Therefore, long duration cultivars are predicted to be more productive in areas where moisture regimes exhibit little change but high temperature is a major crop production constraint. Thus, longer maturing varieties would thus be required to maintain the length of time for total crop development as temperatures warm. On the other hand, short duration cultivars could better escape terminal drought or stress condition that often occurs at the flowering, pod setting and grain filling stages of the crop. 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.

3.3. Effect of sowing dates on chickpea grain yield in the baseline, 2030 s and 2050 s time slice under RCP4.5 and RCP8.5 scenarios

Based on the simulation result, sowing dates is predicted to significantly ($P \leqslant 0.05$) affect chickpea grain yield at both sites in the baseline, 2030 s and 2050 s under RCP4.5 and RCP8.5 scenarios. Early sowing (SSD − 20 days) is predicted to significantly ($P \leqslant 0.05$) increase chickpea grain yield at Sirinka by about 43%, 42% and 48% in the baseline, 2030 s and 2050 s, respectively whereas the increase in chickpea grain yield at Chefa is predicted to be 33%, 40% and 12% across the respective time periods. Early sowing (SSD − 10 days) is also predicted to significantly ($P \leqslant 0.05$) increase chickpea grain yield at Sirinka by about 16%, 19%, and 22% in the baseline, 2030 s and 2050 s, respectively but the increase at Chefa is predicted to be 25%, 29% and 5% across the respective time periods. On the other hand, both the delayed sowing conditions are predicted to decrease chickpea grain yield at both sites in the baseline, 2030 s and 2050 s time periods, respectively. The effect of sowing date on chickpea grain yield was also evaluated under different climate scenarios (baseline, RCP4.5 and RCP8.5 scenarios in 2030 s and 2050 s). According to the result, early sowing (SSD − 20 days) is predicted to significantly ($P \leqslant 0.05$) increase chickpea grain yield at Sirinka by about 43% under the baseline scenario, by about 42% and 41% in 2030 s and by about 46% and 49% in 2050 s under RCP4.5 and RCP8.5 scenarios, respectively whereas the increase in chickpea grain yield at Chefa is predicted to be 33% under the baseline scenario, 39% and 40% in 2030 and 12% and 11% in 2050 under RCP4.5 and RCP8.5 scenarios, respectively. Early sowing (SSD − 10 days) is also predicted to increase chickpea grain yield at Sirinka by about 16% under the baseline scenario, by about 18% and 20% in 2030 s and by about 21% and 23% in 2050 s under RCP4.5 and RCP8.5 scenarios, respectively whereas the increase in chickpea grain yield at Chefa by is predicted to be 25% under the baseline scenario, 33% and 24% in 2030 s and 5% and 4% in 2050 s under RCP4.5 and RCP8.5 scenarios, respectively.

Based on the prediction result, early sowing of chickpea in the semi-arid environments of north-eastern Ethiopia is more advantageous in terms of increasing chickpea grain yield as compared to the current chickpea sowing date and/or the delayed sowing dates. On the other hand, both the delayed sowing conditions are predicted to significantly decrease chickpea grain yield. According to the result, chickpea grain yield under the early sowing (SSD − 20 days) condition is predicted to significantly increase in the baseline, 2030 s and 2050 s. Therefore, early sowing is predicted to be very helpful as it could help the crop to utilize soil moisture in the growing season. As a result, the crop can better escape terminal drought or stress condition that often occurs at flowering and grain filling stages of the crop (Fig. 2).

The reduction in grain yield of chickpea under delayed sowing conditions might be associated to severe water stress or terminal drought condition during the reproductive period of the crop. Leport et al. (1999) also reported that the number of seeds of chickpea plants was significantly reduced as a result of terminal drought. According to the report of Saini and Westgate (2000) reproductive development of plants is highly vulnerable to water deficit. The report also indicated that water stress during the flowering and pod setting stage of the crop could delay or completely inhibit flowering and pod setting through an inhibition of floral induction. When sowing time for chickpea is delayed, the residual soil moisture available to support the crop growth might be depleted on wards which could expose the crop for terminal drought and finally reduce the grain yield. On the other hand, sowing too early may expose the crop to water-logging which is also a major problem for chickpea production particularly in Vertisol. Therefore, it is important to integrate early sowing dates with water drainage techniques such as broad bed and furrow (BBF) in Vertisols. According to the report of Teklu et al. (2004) BBF is recommended and disseminated as a means to overcome the problem of poor drainage to enhance productivity of crops sensitive to water-logging in the central highlands of Ethiopia. Improving drainage might enable early sowing and increase the growth

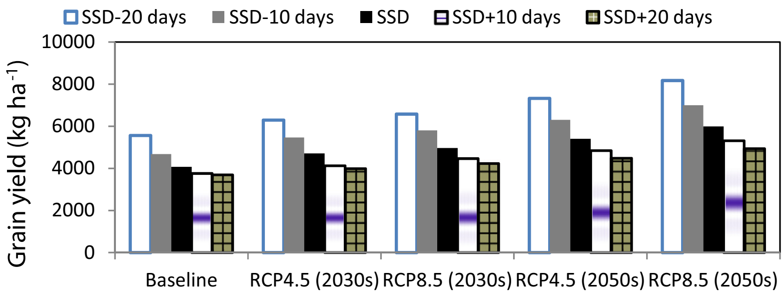

Fig. 2. Effect of sowing date on mean grain yield of chickpea at Sirinka in the baseline, 2030 s and 2050 s time slice under RCP4.5 and RCP8.5 climate scenarios.

period without drought stress, and therefore enhance seed yield. Our result also agrees with previous studies that indicated sowing date is the most frequently varied option (White et al., 2011), which will surely be adjusted to increased grain yield of chickpea under climate change condition. The benefit from early sowing under climate change condition is much higher than its cost of adaptation. Sowing date is a simple and cost effective adaptation option as users can easily shift their sowing time without encoring additional cost of adaptation. Therefore, the study conclude that sowing date for chickpea in the study region and similar agro-ecologies should be advanced at least for 20 days as compared to the standard sowing date (the median sowing date in the sowing window for chickpea).

3.4. Effect of combination of cultivars and sowing dates on chickpea grain yield in the baseline, 2030 s and 2050 s time slice under RCP4.5 and RCP8.5 scenarios

The combination of cultivars and sowing dates are predicted to significantly affect chickpea grain yield at both sites in the baseline, 2030 s and 2050 s time periods. Based on the simulation result, both the early sowing conditions (SSD-20 days and SSD − 10 days) are predicted to significantly ($P \leqslant 0.05$) increase cultivars grain yields at both sites in the baseline, 2030 s and 2050 s time periods. On the other hand, both the delayed sowing conditions are predicted to decrease cultivars grain yields at both sites across the respective time periods. According to the result, early sowing (SSD − 20 days) is predicted to increase grain yield of the short duration cultivar at Sirinka by about 48%, 48% and 54% in the baseline, 2030 s and 2050 s time periods, respectively whereas the increase grain yield of the short duration cultivar at Chefa is predicted to be 26%, 27% and −1% across the respective time periods. Early sowing (SSD − 20 days) is predicted to increase grain yield of the standard cultivar at Sirinka by about 43%, 42% and 48% whereas the increase in grain yield of the standard cultivar at Chefa is predicted to be 33%, 39% and 12% in the baseline, 2030 s and 2050 s time periods, respectively. Grain yield of the long duration cultivar is also predicted to increase at Sirinka by about 31%, 33% and 44% under the same sowing condition whereas the increase grain yield of the long duration cultivar at Chefa is predicted to be 37%, 32% and -2% across the respective time periods. The combination of cultivars and sowing dates are also predicted to significantly affect chickpea grain yield at both sites under the different climate scenarios (baseline, RCP4.5 and RCP8.5 scenarios in 2030 s and 2050 s). According to the result, early sowing (SSD − 20 days) at both sites is predicted to significantly ($P \leqslant 0.05$) increase cultivars grain yields under all the scenarios. On the other hand, delayed sowing at both sites is predicted to significantly decrease cultivars grain yields under all the scenarios. Based on the result, combination of short duration cultivars and early sowing are considered as very important options to increase grain yield of chickpea in areas where terminal moisture stress or drought is major crop production constraint (Table 1).

The early sowing and short duration cultivars are predicted to help chickpea crop to escape terminal drought condition that often occurs at flowering, pod setting and grain filling stages of the crop. On the other hand, the combination of long duration cultivars, standard (medium) cultivars and early sowing conditions are predicted to increase grain yield of chickpea in areas where high temperature is major crop production constraint. Long duration cultivars are more preferred than short duration cultivars under high temperature condition because they can maintain the adverse effect of high temperature on the development and growth stages of the crop. Therefore, crop breeding program should focus on developing both short duration and long duration cultivars that are suitable for the different agroecologies in the region and their sowing date should be advanced as compared to the current chickpea sowing date. In general, the present study showed that sowing date in the semi-arid environments of north-eastern Ethiopia should be advanced at least for 20 days as compared to the present chickpea sowing date and should be combined with suitable cultivars to achieve greater productivity. In agreement with this finding, previous studies indicated that under warmer future climate, earlier sowing is likely to require cultivars with different phenological development than currently used (Soltani and Sinclair, 2012) (Table 2).

3.5. Conclusion

The possibilities for increasing rainfed chickpea productivity was tested by changing sowing date and cultivars of different maturity groups. Based on the result, the highest grain yield at Sirinka is predicted for short duration cultivar whereas

Table 1
Effect of combinations of cultivars and sowing dates on grain yield (kg ha^{-1}) of chickpea at Sirinka in the baseline, 2030 s and 2050 s time slice under RCP4.5 and RCP8.5 scenarios.

Treatments	Baseline yield	% change	2030 s yield (ka ha^{-1})				2050 s yield (ka ha^{-1})			
			RCP4.5	% change	RCP8.5	% change	RCP 4.5	% change	RCP8.5	% change
SC + SSD (control)	1961	–	2315	–	2478	–	2638	–	2941	–
SC + SSD − 20 days	2810	43	3290	42	3503	41	3858	46	4390	49
SC + SSD − 10 days	2267	15	2735	18	2969	20	3197	21	3595	22
SC + SSD + 10 days	1861	−5	2023	−13	2187	−12	2321	−12	2574	−12
SC + SSD + 20 days	1874	−4	2014	−13	2125	−14	2184	−17	2447	−17
SDC + SSD	2183	11	2547	10	2704	9	2947	12	3223	10
SDC + SSD − 20 days	2916	48	3444	49	3636	47	4036	53	4531	54
SDC + SSD − 10 days	2378	21	2878	24	3092	25	3349	27	3727	27
SDC + SSD + 10 days	1931	−2	2080	−10	2309	−7	2486	−6	2710	−8
SDC + SSD + 20 days	1913	−2	2068	−11	2200	−11	2292	−13	2498	−15
LDC + SSD	1851	−6	2132	−8	2324	−6	2351	−11	2631	−11
LDC + SSD − 20 days	2569	31	3069	33	3268	32	3614	37	4112	40
LDC + SSD − 10 days	2068	5	2535	10	2755	11	2864	9	3245	10
LDC + SSD + 10 days	1760	−10	1922	−17	2077	−16	2152	−18	2402	−18
LDC + SSD + 20 days	1820	−7	1912	−17	2033	−18	2047	−22	2339	−20
LSD (p = 0.05)	470	–	569	–	623	–	632	–	767	–

LSD: Least significant difference at 5% probability level: % Change: Percent change in grain yield with reference to the grain yield of the standard cultivar under the standard sowing date. SC, SDC and LDC stand for standard, short and long duration cultivar, respectively.

Table 2
Effects of combinations of cultivars and sowing dates on grain yield (kg ha^{-1}) of chickpea at Chefa in the baseline, 2030 s and 2050 s time slice under RCP4.5 and RCP8.5 scenarios.

Treatments	Baseline yield	% change	2030 s yield				2050 s yield			
			RCP 4.5	% change	RCP8.5	% change	RCP 4.5	% change	RCP8.5	% change
SC + SSD (Control)	3404	–	3810	–	3886	–	4239	–	4471	–
SC + SSD − 20 days	4512	33	5284	39	5426	39	4742	12	4966	11
SC + SSD − 10 days	4252	25	5049	33	4820	24	4470	5	4660	4
SC + SSD + 10 days	3306	−3	3713	−3	3817	−2	4143	−2	4347	−3
SC + SSD + 20 days	2886	−15	3684	−3	3707	−5	4190	−1	4476	−0.1
SDC + SSD	3084	−9	3665	−4	3731	−4	4114	−3	4215	−6
SDC + SSD − 20 days	4306	26	4908	29	4842	25	4185	−1	4432	−1
SDC + SSD − 10 days	3839	13	4412	16	4588	18	4143	−2	4387	−2
SDC + SSD + 10 days	2952	−13	3402	−11	3492	−10	3803	−10	3877	−13
SDC + SSD + 20 days	2665	−22	3262	−14	3355	−14	3667	−13	3884	−13
LDC + SSD	3405	0.1	3848	0.9	3930	−1	4177	−1	4180	−7
LDC + SSD − 20 days	4673	37	4989	31	5141	32	4325	2	4728	−6
LDC + SSD − 10 days	4184	23	4858	28	4739	22	4293	1	4568	2
LDC + SSD + 10 days	3229	−5	3912	3	4001	3	4289	1	4290	−4
LDC + SSD + 20 days	2797	−18	3580	−6	3715	−3	4127	−3	4260	−5
LSD (p = 0.05)	465		466		460		566		590	

LSD: Least significant difference at 5% probability level: % Change: Percent change in grain yield with reference to the grain yield of the standard cultivar under the standard sowing date. SC, SDC and LDC stand for standard, short and long duration cultivar, respectively.

the highest grain yield at Chefa is predicted for long duration cultivar. Early sowing of chickpea at both sites is predicted to significantly increase grain yield as compared to the standard and/or delayed sowing. The study therefore concluded that short duration cultivars are more appropriate in areas where terminal drought is a major constraint for crop production. Short duration cultivars can easily escape terminal drought condition that usually occurs at flowering and grain filling stages of the crop. On the other hand, long duration cultivars are more appropriate in areas where high temperature is a major constraint for crop production. High temperature can speed up growth and development stages of crops and finally shorten their life cycle. This condition ultimately reduces crops productivity. Long duration cultivars can maintain the adverse effect of high temperature on growth and development of crops. Therefore, new chickpea varieties with both shorter and longer growth habits than the current ones are required for the present and future climate conditions. The highest increase in chickpea grain yield in the present and future climate conditions can be achieved through suitable cultivars under early sowing condition. Hence, results of this study could be extended to water-limited and high temperature chickpea growing areas with similar climatic and edaphic conditions. The effectiveness of other crop management options in counteracting the adverse impact of terminal drought and high temperature need to be assessed and quantified in the future.

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Further reading

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