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Exploring climate change impacts and adaptation options for maize production in the Central Rift Valley of Ethiopia using different climate change scenarios and crop models

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Abstract Exploring adaptation strategies for different climate change scenarios to support agricultural production and food security is a major concern to vulnerable regions, including Ethiopia. This study assesses the potential impacts of climate change on maize yield and explores specific adaptation options under climate change scenarios for the Central Rift Valley of Ethiopia by mid-century. Impacts and adaptation options were evaluated using three General Circulation Models (GCMs) in combination with two Representative Concentration Pathways (RCPs) and two crop models. Results indicate that maize yield decreases on average by 20 % in 2050s relative to the baseline (1980–2009) due to climate change. A negative impact on yield is very likely, while the extent of impact is more uncertain. The share in uncertainties of impact projections was higher for the three GCMs than it was for the two RCPs and two crop models used in this study. Increasing nitrogen fertilization and use of irrigation were assessed as potentially effective adaptation options, which would offset negative impacts. However, the response of yields to increased fertilizer and irrigation will be less for climate change scenarios than under the baseline. Changes in planting dates also reduced negative impacts, while changing the maturity type of maize cultivars was not effective in most scenarios. The multi-model based analysis allowed estimating climate change impact and adaptation uncertainties, which can provide valuable insights and guidance for adaptation planning.

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1 Introduction

Agricultural systems are inherently vulnerable to climate variability (Challinor et al. 2007b; Müller et al. 2011) and climate change is expected to increase this vulnerability (Rosenzweig et al. 2014; Thornton et al. 2010). Various global and regional studies warn that progressive climate change is expected to negatively affect crop productivity in most parts of the world (Wheeler and von Braun 2013) and particularly in sub-Saharan Africa (Cairns et al. 2013; Cooper and Coe 2011; Waha et al. 2012; Müller et al. 2011). Ethiopia is among the most vulnerable countries in sub-Saharan Africa due to its great reliance on climate sensitive sectors, particularly agriculture (Conway and Schipper 2011; Thornton et al. 2006).

Various studies indicated that adaptation to climate change has the potential to significantly reduce negative impacts on crop production (e.g. Challinor et al. 2014; Howden et al. 2007;). However, previous studies on climate change in Ethiopia have often been limited to assessing impacts on current agricultural systems without accounting for potential adaptation. For example, Arndt et al. (2011) estimated the economic impacts of climate change on Ethiopian agriculture using an econometric approach without considering adaptation options. Few studies addressed both climate change impacts and adaptation in Ethiopia, mainly based on household survey approaches (e.g. Bryan et al. 2009). Our study aims to combine assessment of both impacts and adaptations options using crop and climate modelling and to provide detail insights.

Climate change impact and adaptation studies are inherently uncertain due to partial understanding or oversimplification of processes incorporated in climate models, downscaling methods and imperfect crop simulation models (Asseng et al. 2013; Osborne et al. 2013). While using multiple climate models has become a common approach in climate risk assessments (Tebaldi and Knutti 2007), most studies have applied a single crop model, which fails to represent uncertainties known to exist in crop responses to climate change (Asseng et al. 2013; Bassu et al. 2014; Rötter et al. 2011). Our study applied two crop models in combination with climate projections from three General Circulation Models (GCMs) and two Representative Concentration Pathways (RCPs) (Moss et al. 2010) to assess the range of potential outcomes as a measure of the uncertainty in climate change impact projections for maize. The main objectives of our study were (i) to assess the potential impacts of climate change on maize yield and (ii) to explore alternative adaptation options under different climate change scenarios in the Central Rift Valley of Ethiopia.

2 Materials and methods

2.1 The study area

The study was conducted in the Central Rift Valley of Ethiopia (CRV), located about 120 km south of Addis Ababa and characterized by an alternating topography with a central valley floor at 1500–1800 m.a.s.l., bounded by western and eastern escarpments. The CRV represents a closed basin between 38°08′ and 39°08′E and 7°01′ and 8°03′N comprising an area of ca. 1.03 million hectares. Its annual rainfall ranges from less than 500 mm in the valley floor to more than 1000 mm at higher altitudes and the annual mean temperature is about 18 °C. Soil groups of the CRV are Andosol, Luvisol, Fluvisol, Cambisol and Solonetzes (Abdelkadir and Yimer 2011). We choose Andosols for this study, which is the dominant soil in the maize growing areas of the CRV (see appendix for detailed soil description).

2.2 Climate change scenarios

Daily measured weather data for the present climate, hereafter referred to as baseline, was obtained from the National Meteorological Agency of Ethiopia (http://www.ethiomet.gov.et) for the period 1980–2009. Climate change scenarios were derived from three GCMs: CanESM2, CSIRO-MK3-6-0 and HadGEM2-ES (see appendix for details), in combination with RCPs (Moss et al. 2010). The GCMs were selected based on the contrasting shifts they projected with respect to temperature (T) and precipitation (P). To make the selection, we examined the projections of a range of GCMs for various emissions scenarios jointly by plotting their projected changes in T and P and chose those that best represented the window of changes, i.e. the driest, wettest, hottest and coolest scenarios. The time horizon for the climate change scenario analysis was for the mid-century (2040–2069), hereafter referred to as "2050s". We used two of the four RCPs: RCP4.5 (a relatively modest increase in greenhouse gas concentrations) and RCP8.5 (a rapid increase in greenhouse gas concentrations). RCP4.5 refers to a pathway in which the radiative forcing of greenhouse gases reaches 4.5 W/m^2 in the year 2100 relative to pre-industrial levels, while RCP8.5 describes a pathway in which radiative forcing reaches 8.5 W/m^2 in the year 2100, relative to the pre-industrial levels (Van Vuuren et al. 2011). The CO_2 concentration for the RCP4.5 and RCP8.5 were 499 and 571 ppm by the 2050s, respectively, whereas the baseline CO_2 concentration used in this study was 360 ppm.

Climate scenarios were generated by changing the baseline climate data based on outputs from the GCMs/RCPs using the "Delta method" (Wilby et al. 2004). With the delta method, changes in rainfall are created by multiplying the rainfall scenario change factors with the baseline daily values, while changes in minimum and maximum daily temperature are obtained by adding the temperature change factors to the baseline values (Ruane et al. 2013). A projected change in annual and seasonal rainfall and mean temperature for the different GCMs and RCPs by 2050s is presented in Fig. 1 for the selected climate change scenarios.

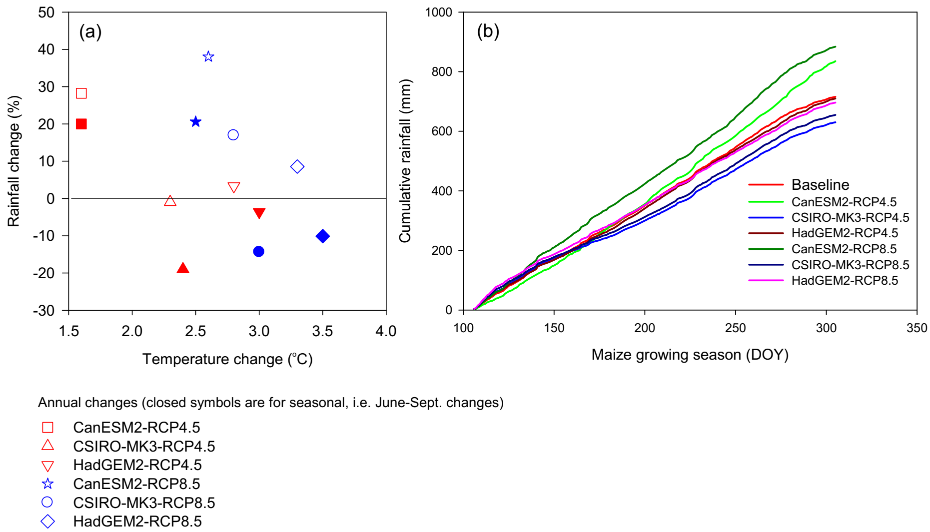

Fig. 1 Changes in annual and seasonal rainfall and temperature as projected by different climate models in 2050s (2040–2069) relative to the base period (1980–2009) (**a**) and associated cumulative rainfall during the growing season of maize (**b**) in the CRV, Ethiopia

2.3 Crop management scenarios for adaptation

(i) Planting dates:

We determined sowing dates for the baseline and climate change scenarios based on the first occurrence of rainfall within the planting window (between April 15 and July 7) meeting the sowing criteria, i.e. at least 40 mm of rainfall accumulated within 4 rainy days (Kipkorir et al. 2007; Mugalavai et al. 2008; Raes et al. 2004). Optimum planting dates, which provided the highest yield were determined from simulations of the baseline and the climate change scenarios using sowing dates of weekly intervals around the earliest and latest possible sowing date within the planting window. Both the DSSAT and WOFOST crop models (Section 2.4) were used for the simulation.

(ii) Nutrient management:

We simulated the impacts of three levels of nitrogen fertilizer i.e. low (20 kg N/ha), moderate to high (80 kg N/ha) and very high fertilization (no nitrogen limitation), while P and K were assumed to be adequately supplied in all cases. The low nitrogen (20 kg/ha) is approximately the average application rate currently used for maize in Ethiopia (Spielman 2008) and the moderate and very high nitrogen fertilizer levels were considered, as potential future options for climate change adaptations in the 2050s. The source of nitrogen was assumed to be urea, which is currently the most frequently applied nitrogen fertilizer in Ethiopia. Nitrogen application for low and moderate doses was split: 50 % at planting and 50 % at 30 days after planting, which is common practice in the study area.

(iii) Irrigation:

Staple crops are commonly produced under rainfed conditions in the study area. However, irrigated vegetable production is rapidly increasing near suitable ground water and surface water resources in the area (Van Halsema et al. 2011), and points at possibilities for irrigated staple production as well. Considering the prospects for irrigation, we assessed simulations under rainfed and full irrigation (no-water stress) and no nutrient limitation conditions to gain insight into the possibilities of optimum management (full irrigation and full fertilization) option to reduce the impacts of climate change. We also evaluated effects of supplementary irrigation during moisture sensitive growth stages of maize (flowering and grain filling) with moderate (80 kg/ha) fertilizer application assuming that this combination of management options may be more realistic at smallholder farm conditions.

(iv) Cultivars:

One of the most common practices of farmers to cope with current climate variability is to replace medium maturing cultivars with early maturing cultivars when the main rainy season starts late (Kassie et al. 2013). We evaluated the impact of choosing an early and a medium maturing cultivar under future climate change scenarios.

2.4 Crop simulation models

In this study, we used the CERES-maize model embedded in Decision Support Systems for Agrotechnology Transfer (DSSAT, v4.5) and WOrld FOod STudies (WOFOST, v7.1). These models were chosen because they are well accepted and widely used in the crop modeling community to assess the impacts of climate change and evaluate various adaptation options (Tubiello and Ewert 2002). In addition, they have been tested and used in the environments of Sub-Saharan Africa including Ethiopia (e.g. Jones and Thornton 2003 for DSSAT; Rötter et al. 1997 for WOFOST). Both DSSAT and WOFOST are designed to simulate crop growth as a function of crop features and management, weather conditions and soil characteristics. However, the two models differ in the detail of describing various crop-growth processes. For instance, DSSAT uses a relatively simple radiation use efficiency approach to model net photosynthesis, while WOFOST uses a more detailed approach for describing photosynthesis and respiration (Palosuo et al. 2011). Details for modeling approaches of the two models are presented in the appendix. The two models were previously calibrated and tested for different maize cultivars in the CRV of Ethiopia in a study of climate variability and yield gap analysis (Kassie et al. 2014). A widely cultivated medium maturing maize cultivar (BH540) was used for the analysis of the various climate change adaptation options, while cultivar choice option also included an early maturing cultivar, i.e., Melkassa 1 (See appendix for cultivar parameters).

To account for the effects of elevated CO_2 on crop growth and yield, simulations were carried out by keeping the CO_2 concentration at the current level for the baseline period and by changing the CO_2 concentrations for each climate change scenario to their corresponding level (Section 2.2).

3 Results

3.1 Projected changes in temperature and rainfall

The baseline average annual minimum temperature is 12.6 °C and maximum temperature is 27.1 °C with mean annual temperature of 19.9 °C. The average annual minimum temperature is expected to increase by 2.2 to 3.5 °C and the maximum temperature by 1.1 to 3.2 °C. As a result, the mean annual temperature is expected to increase by 1.6 to 3.3 °C in 2050s (Fig. 1). The lowest and highest change in annual mean temperature is projected by CanESM2 and HadGEM2 models, respectively. For the main rainy season (June–September), the average minimum temperature is likely to increase by 1.9 to 3.3 °C and the maximum temperature by 1.2 to 3.6 °C, resulting in mean seasonal temperature changes of 1.6 to 3.5 °C in 2050s.

The baseline annual rainfall is about 960 mm and seasonal rainfall (June–September) is 470 mm. Projected changes for the annual rainfall varies widely between −1 and 38 %. For the main rainy season (June–September), four of the six climate change scenarios (HadGEM2 and CSIRO-MK3 climate models in combination with the RCP4.5 and RCP8.5) projected rainfall to decrease by 4 to 20 % whereas two of the scenarios (CanESM2 climate model in combination with RCP4.5 and RCP8.5) projected an increase of rainfall by 20–21 %.

3.2 Impacts of climate change on maize yield

Simulated mean yield for maize ranges from 7.6 to 8.3 Mg/ha in the baseline scenario (a medium maturing cultivar with no nitrogen limitation under rain-fed and current climate conditions) and from 5.4 to 8.1 Mg/ha in the climate change scenarios in the 2050s (Fig. 2a). All climate change scenarios and both crop models used in this study projected a reduction in mean maize yield relative to the baseline climate (Fig. 2b). The overall mean decline in maize yield of the climate change scenarios and crop models was 20 % in 2050s relative to the baseline. Uncertainty is higher among the GCMs (−8 to −28 %, averaged over crop models and RCPs) than between crop models (−19 to −20 %) or RCPs (−17 to −22 %, averaged over GCMs and crop models). Increased atmospheric CO_2 concentration has little effect (+5.3 %) on maize yield.

The future growing period for maize was shorter than in the baseline scenario, from 14 days (in CanESM2) up to 33 days (in HadGEM2) (Table 1). The number of days with which the crop growth period decreased was similar for DSSAT (16–31 days) and WOFOST (14–33 days), while it was higher for RCP8.5 (25–33 days) than for RCP4.5 (16–26 days).

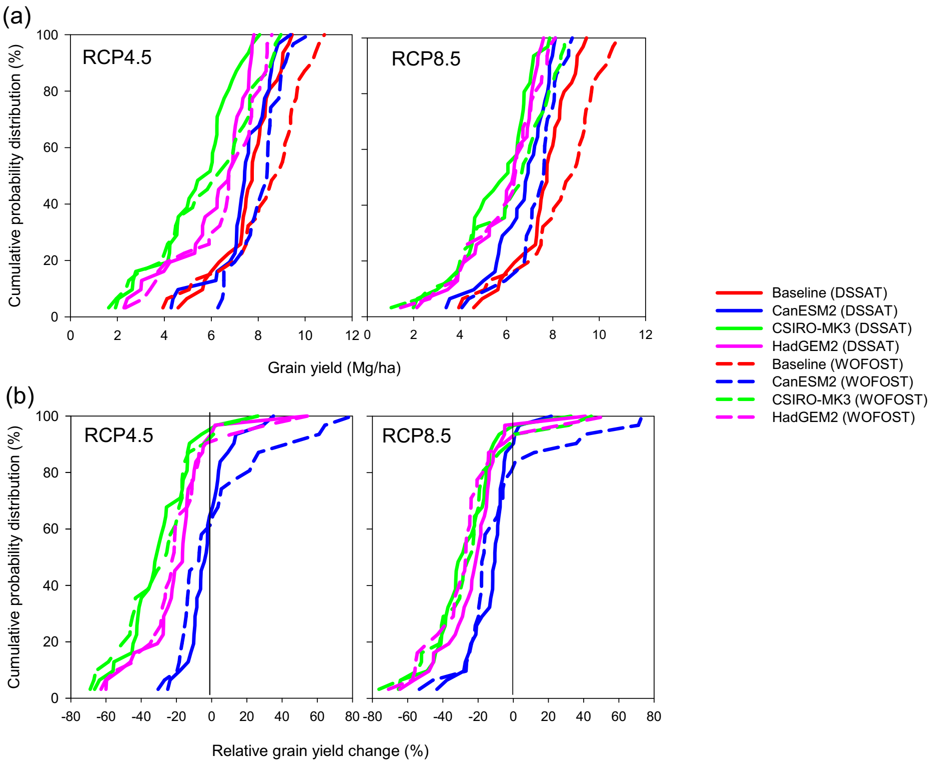

Fig. 2 Cumulative probability distribution of simulated grain yield (**a**) and yield changes for future climate change scenarios relative to the baseline period (**b**) as simulated with DSSAT and WOFOST crop models

3.3 Adaptation options

3.3.1 Change in planting dates

Optimum planting dates which provided maximum yields occurred between end of May (day of year 141) and mid-June (day of year 169) for the baseline climate while maximum yields were simulated with planting dates between mid-June (day of year 162) and end of June (day of year 183) in climate change scenarios with slight differences between the two crop models (Fig. 3). Rainfall in June and July was reduced by 6 and 5 % (averaged over climate change scenarios) respectively, which in combination with the increased temperature reduced yields for the earliest planting dates. In contrast, rainfall during August, September and October increased by 2, 4 and 17 % in the future scenarios, respectively, which favored maize growth with late planting dates. The increase in temperature was also highest in June and July (2.6 and 2.7 °C,

Table 1 Changes in maize growth duration (in days) under the various climate change scenarios in the Central Rift Valley, Ethiopia

Crop model	CanESM4.5	CSIRO-MK4.5	HadGEM4.5	CanESM8.5	CSIRO-MK4.5	HadGEM8.5
DSSAT	−16	−23	−26	−25	−27	−31
WOFOST	−14	−23	−28	−26	−28	−33

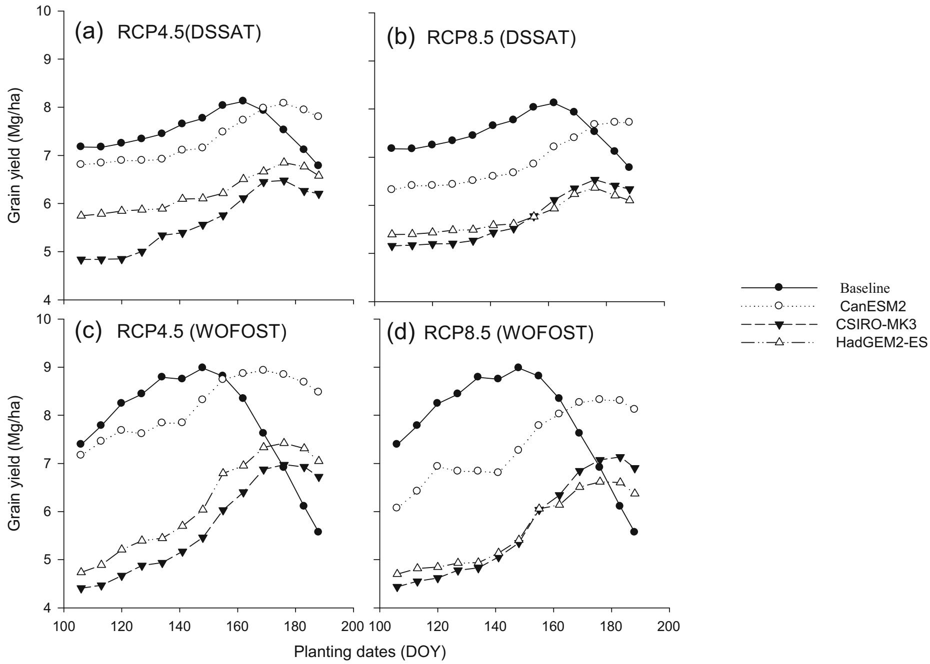

Fig. 3 Effects of planting dates on maize grain yield under the baseline and future climate change scenarios in the CRV, Ethiopia, as simulated with DSSAT and WOFOST. Each value is the average of 30 years simulation for baseline climate and climate change scenarios

respectively) and lowest in August and September (2.5 °C). It appeared that late planting has an advantage in reducing heat stress and dry spell effects at the critical growth stage.

3.3.2 Nitrogen application

In all climate change scenarios, higher nitrogen levels increased maize yields, but full nitrogen supply (no nitrogen limitation) provided little additional yield increase (12–17 % across the climate change scenarios) compared to 80 kg N/ha (Fig. 4). For RCP4.5, simulated yield with 20 kg N/ha varied between 2.6 and 3.4 Mg/ha and with 80 kg N/ha between 4.8 and 6.3 Mg/ha (increase in yield by 85–89 %) while for RCP8.5, simulated yield with 20 kg N/ha varied between 2.6 and 3.2 Mg/ha and with 80 kg N/ha between 5.1 and 5.7 Mg/ha (increase in yield by 78–86 %). Overall, increasing the nitrogen rate from 20 to 80 kg/ha increased yields by 78–89 % in the various climate change scenarios. However, yields simulated with 20 kg N/ha in the climate change scenarios were lower than those with 20 kg N/ha under baseline climate; the same also holds for the yields simulated with 80 kg N/ha (Fig. 4), which suggests that crop yields will be less responsive to nitrogen under climate change conditions.

3.3.3 Irrigation application

Application of full irrigation resulted in a modest increase in yield under the baseline and climate change scenarios (Fig. 5). Yields increased by 11–16 % (ranges are for crop models) under the baseline scenario. It did not significantly increase under the wet scenarios (CanESM2), while it increased by 15–22 % under HadGEM2 and by 22–39 % under

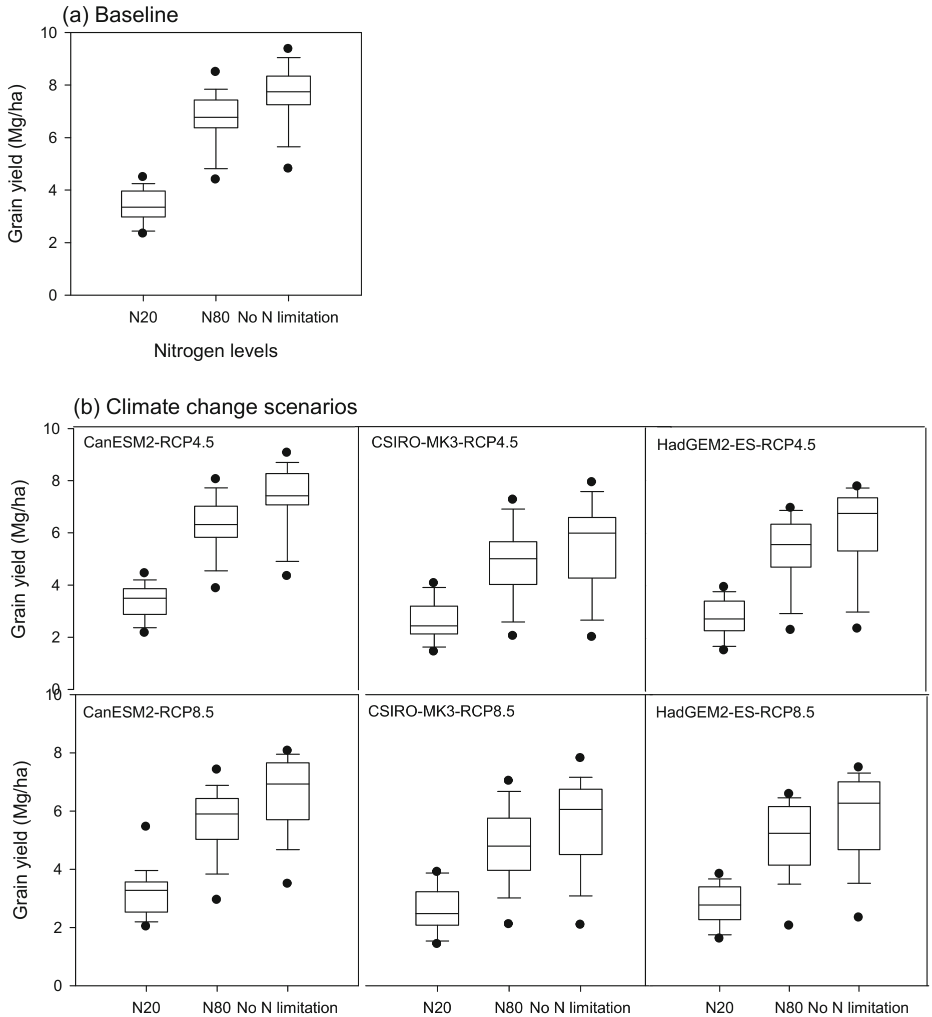

Fig. 4 Effects of nitrogen fertilization rates on maize grain yield simulated with the DSSAT crop model under the baseline and future climate change scenarios. N20, N80 and No-N stress represent nitrogen levels of 20 kg/ha, 80 kg/ha and no nitrogen stress scenarios, respectively

CSIRO-MK3. Simulated water-limited yield ranged from 5.4 to 8.1 Mg/ha, while yields with irrigation (potential yield) ranged from 7.0 to 8.4 Mg/ha across the crop models and climate change scenarios. The inter-annual variability of yield under climate change scenarios was also reduced with full irrigation compared to rain-fed conditions (CV was 12.5–37.4 % for rain-fed and 7.0–8.5 % for irrigation). However, yields with irrigation under climate change scenarios are lower than yields simulated with irrigation for the baseline climate (Fig. 5), implying that irrigation is less effective under climate change conditions than under the baseline. Full irrigation with high fertilization may not be affordable for many smallholder farmers. However, supplementary irrigation could help to increase yields by 5–21 % relative to the rain-fed production in climate change scenarios (Table 2); thereby reducing the impact of climate change to 5–15 %.

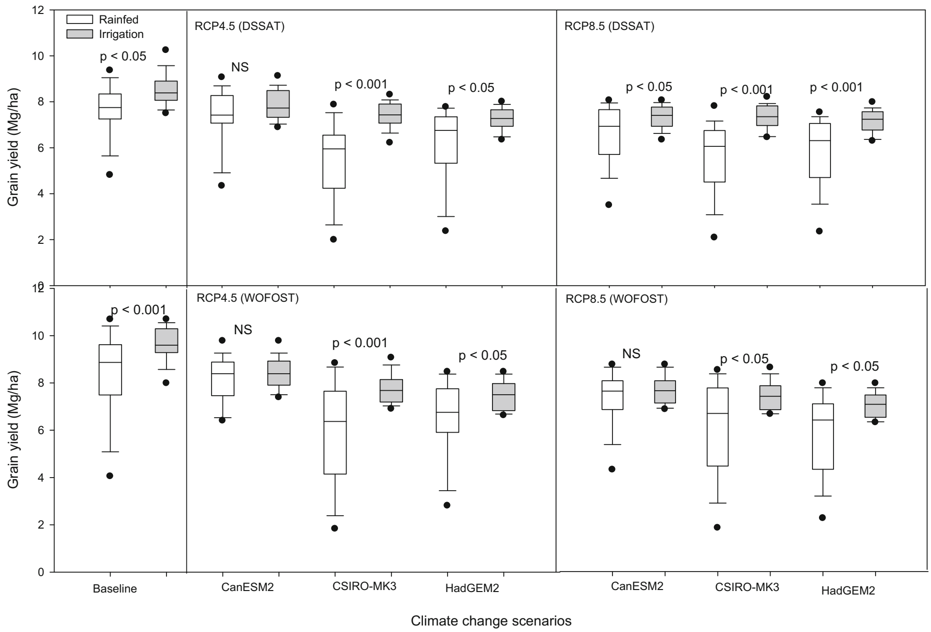

Fig. 5 Effect of irrigation on maize grain yields compared to rainfed under the baseline and future climate change scenarios with no nutrient limitation conditions as simulated with the DSSAT and WOFOST crop models. NS indicates a statistically non-significant difference

3.3.4 Changes in cultivar

Under the baseline, the medium maturing variety yielded significantly more than an early maturing variety (7.6–8.3 Mg/ha versus 6.8–7.2 Mg/ha, based on the two crop models) (Fig. 6). Under climate change scenarios, only with the CanESM2 (wet scenario), the medium maturing variety yielded significantly higher (16–20 %) than the early variety. For all other climate change scenarios yields were lower for the early maturing cultivar than the medium maturing, but effects were not significant. This implied that changing the maturity class of the cultivars would generally not be a suitable adaptation option for the projected climate change.

Table 2 Simulated effects of supplementary irrigation on maize yield (Mg/ha) compared to rain-fed production under baseline climate and climate change scenarios in the CRV, Ethiopia, using DSSAT

	Baseline	RCP4.5			RCP8.5		
		CanESM2	CSIRO-MK3	HadGEM2	CanESM2	CSIRO-MK3	HadGEM2
Rainfed	6.7	6.3	4.8	5.3	5.7	4.9	5.1
Supplementary Irrigation	7.2	6.6	5.7	6.0	6.1	5.9	5.9
Yield change (%)	7.4	4.8	18.8	13.2	7.0	20.4	15.7

Nitrogen application was 80 kg/ha and the supplementary irrigation simulations received 70 mm of water

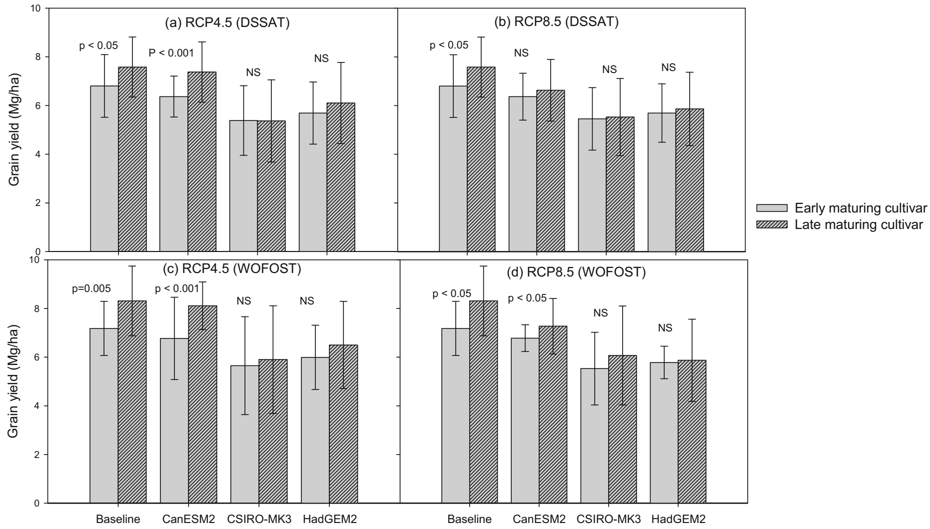

Fig. 6 Simulated grain yields (with DSSAT and WOFOST) for early and late maturing cultivars under the baseline and future climate change scenarios

4 Discussion

4.1 Methodology of climate change impact assessment

Since a single crop model can only partially represent uncertainties known to exist in crop responses to climate change (Asseng et al. 2013; Rötter et al. 2011), we used two crop models which, in combination with selected climate scenarios, enabled us to use ranges of outcomes as initial estimates of impact uncertainties. It is now widely assumed that a multiple modeling approach can provide better information and guidance for agricultural planners and policy makers (Rosenzweig et al. 2013). Note, that DSSAT and WOFOST, like many other crop simulation models, lack the capability of quantifying impacts of occurrence of pests and diseases on crop growth. Such shortcoming needs to be taken into account in interpreting crop model simulation results, especially in low-yielding environments with limited crop protection such as in the CRV.

4.2 Climate change impacts and uncertainties

For the past five decades, maize yield in Ethiopia was steady with an increase from 1 t/ha to only 1.6 t/ha (www.faostat.fao.org). Our analysis for climate change scenarios in the CRV indicated that future yields are likely to be negatively affected. This implies that food security in Ethiopia will greatly deteriorate in a business-as-usual scenario and with a population that is projected to increase from 94 million in 2013 to approximately 187 million in 2050 (UN 2013).

Agricultural impact projections are subject to uncertainty (Whitfield 2013), which arises from uncertainty in processes and the various tools used in impact assessment such as the climate and crop models, emission scenarios and down-scaling techniques. As a result, literature commonly shows a wide range of potential impacts of climate change for the same region. For example, Reilly and Schimmelpfennig (1999) estimated that maize yields in Africa may change between −98 and +16 % due to the impacts of climate change and elevated CO_2 concentration, while Thornton et al. (2010) estimate a much smaller range of −25 to −6 %. Because impact studies often differ by climate scenarios, time horizon and, more generally assessment methodologies, it is difficult to directly compare results with those from other studies (see e.g. White et al. 2011). However, the order of magnitude of the yield change we found is broadly consistent with other studies in tropical and sub-tropical regions. For instance, Schlenker and Lobell (2010), indicated maize yield reductions of about 22 % in sub-Saharan Africa by 2050s and many others reported nearly similar ranges of yield reduction (e.g. Jones and Thornton 2009) The main driving factor for changes in maize yield in the CRV is increasing temperature resulting in a growing period shortened by 14–33 days across the climate change scenarios.

Uncertainties in climate change impact studies are generally associated with climate scenarios (i.e. GCM projections and GHG emission scenarios (see Osborne et al. 2013; Whitfield 2013). In addition, there is uncertainty from crop models (Rötter et al. 2011), adaptation packages, and agricultural development pathways (Rosenzweig et al. 2013). Impact of climate change on maize yields in the CRV will be higher between different GCMs (−28 to −8 %, averaged over RCPs and crop models) than between different RCPs (−22 to −17 %, averaged over GCMs and crop models) and crop models (−20 to −19 %, averaged over GCMs and RCPs). Thus, based on our selection of models, it can be concluded that GCMs are the main source of the uncertainly, which is consistent with the observation that uncertainties from GCMs generally dominate regional impact assessments for mid-century (Hawkins and Sutton 2011), although this may not always be the case (Asseng et al. 2013; Rosenzweig et al. 2014).

4.3 Adaptation options

Adjusting planting dates is among the most widely studied strategy of adapting to climate change (White et al. 2011). Currently, CRV farmers practice shifting planting dates based on the onset of the rainy season; however, crop failure due to false starts of the rainfall season is a common risk (Kassie et al. 2013). Our analysis indicated that optimum planting dates for future climate occurred later than the optimum planting dates under the baseline climate. For the early planting dates (mid-April to May) under future climate, critical growth stages of maize (i.e. during June and July) faced a decline in rainfall and increased temperature. Hence, the late planting dates provided the advantage for crops to avoid heat and drought stress at the early growth stage. In agreement with our results, Tachie-Obeng et al. (2010) reported an increase in maize yields with delayed planting dates for climate change scenarios in Cameroon.

The response of yield to nitrogen applications is higher for the baseline climate than future climate change scenarios, which implies that future climate will reduce the nutrient uptake efficiency and response to nitrogen applications. Similar to our results, Luo et al. (2009) reported that changing the nitrogen levels from 25 to 75 kg/ha increased wheat yield under climate change in Australia but the projected yield increase was less than for the baseline. Similarly, Turner and Rao (2013); indicated that increasing nitrogen fertilizer rate from 20 to 80 kg/ha under a 3 °C temperature rise increased yields of sorghum by 15–70 % in Kenya, but that was less than the yield increase with the same increased N inputs under the baseline climate. Maize yield was significantly higher with irrigation under climate change except for the wet scenarios (CanESM2). An application of supplementary irrigation during moisture sensitive growth stages of maize (flowering and grain filling) could help reducing the negative impacts of climate change. However, in general, the contribution of irrigation to increase yield will decrease due to climate change compared to a baseline climate. Our study is not detailed enough to suggest specific implications of climate change on future irrigated agriculture, however, a study in the CRV showed that the increased temperature and change in rainfall patterns will alter the evapotranspiration and reduce water availability (Getnet et al. 2014); therefore, options for more irrigated agriculture may be limited. The magnitude of climate change impacts will differ between crops and cultivars (Challinor et al. 2007a) and hence the choice of cultivars which fit best with the changing climate is required. Our analysis indicates that yields of medium and early maturing cultivars were significantly different with the baseline climate, but showed no difference under climate change scenarios except for the wet scenario (CanESM2). This implies that climate change will disfavor the medium maturing cultivars more than the early maturing cultivars due to a shortened growing period. Both the early and medium maturing cultivars will suffer with climate change. This implies that changing the maturity class of current cultivars will not be an option to mitigate projected climate change impacts.

5 Conclusions

Business-as-usual scenario will lead to worsen food insecurity in Ethiopia in face of climate change. In this study, we have shown that maize, one of the staple crops, is expected to decrease in yield by 20 % due to climate change by 2050s relative to the baseline. While the negative impact of climate change on maize yields is very likely, there is an uncertainty ranging from −29 to −2 %. The share in uncertainties of impact projections is higher for the three GCMs than it is for the two RCPs and two crop models used in this study. The projected decrease in maize yield is mainly caused by increased temperature and reduced growing season rainfall, which resulted in a shortened growing period of maize by 9−22 %. Impact of increased temperature is more pronounced than the impact of rainfall changes.

Adaptation options like increasing nitrogen fertilization, the use of irrigation and changes in planting dates can compensate for some of the negative impacts of climate change on maize production in the CRV. However, the response of yield to increased nitrogen fertilization and irrigation supply will be less for climate change scenarios than for the baseline climate. Some of the adaptation options such as irrigation and nitrogen fertilization may involve considerable costs and will require additional economic feasibility and sustainability assessments. Future research therefore needs to include socio-economic effects of the various adaptation options at farm level. The multi-model based analysis allowed the estimation of some of the climate change impact and adaptation uncertainties, which can provide valuable insights and guidance for adaptation planning processes.

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