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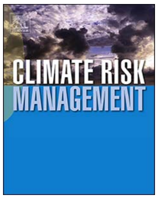

Evaluating the impact of future climate change on irrigated maize production in Kansas

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ABSTRACT

The United States southern and central High Plains including western Kansas are experiencing declining ground water supplies from the Ogallala as a result of withdrawals for irrigation exceeding annual recharge, this situation will be exacerbated by future climate change. The purpose of this simulation based study was to 1) assess the impact of future climate change on maize (*Zea mays* L.) yield in western Kansas; and 2) evaluate and understand the possible impacts of climate change on maize irrigation water productivity, transpiration, evapotranspiration and days to maturity. The Crop Estimation through Resource and Environment Synthesis (CERES-Maize) crop model within the Decision Support System for Agrotechnology Transfer Cropping Systems Model (DSSAT-CSM) was used in combination with multiple Global Climate Models under two Representative Concentration Pathways (RCPs), and two irrigation scenarios [full (450 mm) and deficit (300)] under three planting dates [early (20th April), normal (5th May) and late (15th May)]. Results showed that maize yield during the mid-21st century will decline relative to the present on average by 18–33% under RCP4.5 and 37–46% under RCP8.5. The yield decline might be caused mainly by shortening of the growing period (9–18% decline in days to maturity), attributed to elevated temperatures. The reduction in transpiration relative to the baseline reached 15% for RCP8.5 under deficit irrigation whereas the reduction was minimal (1–7%) under full irrigation. Indicating that significant yield reductions might occur due to combined effects of deficit irrigation and shortening of the maturity period. Yield increase due to elevated CO_2 concentration [CO_2] might be masked by the increased temperatures. The current study showed large disparity in simulated yield among the various GCMs. Planting date did not substantially improve yield but there was less simulation variability among GCMs with early planting compared to normal and late planting. There was no substantial difference among the planting dates for water productivity, however, there was a slight tendency of improvement in irrigation water productivity for deficit irrigation under early planting compared to normal and late planting. Under all planting dates and RCPs, the irrigation water productivity of maize under deficit irrigation was slightly higher than that under full irrigation. The difference in irrigation water productivity of maize between the deficit and full irrigation was larger for early compared to normal and late planting. These differences justify that early planting may be suitable under future climate compared to late planting even though the simulated yield with early planting under similar RCPs and irrigation levels are not significantly different from late planting.

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1. Introduction

Global atmospheric concentrations of greenhouse gasses have significantly increased relative to pre-industrial times (Miao et al., 2013). As a result, greenhouse gas forcing is the main cause of the warming of the atmosphere during the past decades (IPCC, 2007). This warming is expected to substantially alter the climate system and change global food production (e.g., Olesen and Bindi, 2002) mainly because temperatures are predicted to increase which in turn will alter the precipitation pattern and increase the frequency of extreme events such as drought (Harrison et al., 2014).

Climate change will substantially affect productivity of major staple food crops such as maize (Jones and Thornton, 2003; Tao and Zhang, 2010; Ruane et al., 2013; Bassu et al., 2014) because growth and development of crops are mainly dependent on sunlight, temperature, and water (Chen et al., 2013). Climate change may modify precipitation, soil water, runoff, and may reduce crop maturation period and increase yield variability and could reduce areas suitable for the production of many crops (Olesen and Bindi, 2002).

Maize is one of the major commercial crops grown under irrigation in western Kansas. Rainfall covers only a portion of the crop evapotranspiration, and irrigation supplies a significant proportion of crop water needs. The Ogallala aquifer is the main source of irrigation; however, water levels in the Ogallala aquifer have been declining due to water withdrawals for irrigation exceeding mean annual recharge (McGuire, 2012). The demand for water under future climate may increase because of frequent occurrence of extreme weather events such as severe droughts and thus more water may be required in dry climatic conditions and severe heat waves (Olesen and Bindi, 2002). The fate of maize under changing climate is therefore compounded by over extraction of the groundwater and occurrence of extreme weather events. Therefore, there is a need to understand how irrigated maize production particularly in western Kansas and regions of the south and central High Plains might respond to the combined effects of constrained water supplies and extreme weather events.

The CERES-Maize model within the Decision Support System for Agrotechnology Transfer Cropping Systems Model (DSSAT-CSM) (Jones and Kiniry, 1986; Ritchie et al., 1998; Jones et al., 2003; Hoogenboom et al., 2004, 2010) was used in combination with multiple global climate models to assess the impact of climate change on maize productivity under future climate. Unlike many models, the current version of DSSATv4.6 is suitable to run continuous and sequential cropping systems along with many GCMs, RCPs, planting dates and irrigation scenarios taking into account changes in soil water. The DSSAT-CSM-CERES-Maize model has been applied in exploring possible impacts of climate variability and change on crop yield and maturity, evapotranspiration, crop water productivity and future food security issues (Jones and Thornton, 2003; Kang et al., 2009; Estes et al., 2013; Ruane et al., 2013; Araya et al., 2015; Welikhe et al., 2016). Global climate models (GCM) can be used as input in validated crop models to provide a wide range of plausible yield impacts under future agricultural production (Ruane et al., 2014).

The objectives of this study were to:1) assess the impact of climate change on maize productivity during the mid-century period (2040–2069) in relation to the baseline (1980–2009) using 20 Global Climate Models (GCMs), two Representative Concentration Pathways (RCPs) with deficit and full irrigation under three planting dates; and 2) evaluate and understand the possible impacts of climate change on maize irrigation water productivity, transpiration, evapotranspiration and days to maturity.

2. Materials and methods

2.1. Study area

This study was conducted at the Kansas State University Southwest Research-Extension Center, near Garden City with geographical location of 38°01′20.87″N, 100°49″26.95 W, elevation of 887 m above mean sea level, Kansas. The site is categorized as semi-arid with long-term mean annual rainfall and reference evapotranspiration (ETo) of 445 and 1810 mm respectively (Klocke et al., 2011). It has a frost-free period of about 170 days (Klocke et al., 2012). The annual precipitation meets only about 35% of the reference evapotranspiration (ETo) whereas the growing season (May to October) precipitation meets only about 29–48% of ETo. The long-term seasonal (May to October) average rainfall and ETo are 349 and 962 mm, respectively.

The dominant soil type of the study area is Ulysses silt loam with organic matter content of 1.5% and pH of 8.1 (Klocke et al., 2011). Soil survey reports showed that silt loam is a major soil texture in western Kansas. The study area is flat with slopes of less than 2%. The soil water characteristics such as wilting point (13–16 vol%), field capacity (30–35 vol%), and saturation (44–48 vol%) were estimated based on pedo-transfer functions (Saxton et al., 1986).

2.2. Climate scenarios

The long-term (1980–2010) baseline observation data that included minimum and maximum temperatures, daily precipitation and solar radiation for Garden City were obtained from the High Plains Regional Climate Center (http://www.hprcc.unl.edu/). Simulations of future climate scenarios were based upon the observed baseline climate. It is believed that climate projections based on global climate models could provide wide ranges of possible estimates of impacts (Ruane et al., 2013). Climate projections based on multiple GCMs were assumed to provide estimates of future actual climate (Diekkrüger et al., 1995; IPCC, 2001; Hanson et al., 2004; Kersebaum et al., 2007; Meehl et al., 2007; Tao et al., 2009; Taylor et al., 2009; Wilby et al., 2009; Duan and Phillips, 2010; HLPE, 2012; Miao et al., 2013, 2014; IPCC, 2013).

The mid-century (2040–2069) climate scenarios were generated based on Agricultural Model Intercomparison and Improvement Project (AgMIP) climate team methodology presented in AgMIP (2013). Accordingly, climate scenarios were created from the