Ecological Engineering 82 (2015) 555–565

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Predicting changes in yield and water use in the production of corn in the United States under climate change scenarios

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ARTICLE INFO

Article history:
Received 21 October 2014
Received in revised form 7 April 2015
Accepted 23 May 2015
Available online 13 June 2015

Keywords:
CERES-Maize
Agricultural production
Climate change scenarios

ABSTRACT

Changes in climate will have significant implications for agricultural production in the United States. Increased temperatures, as well as altered hydrologic cycles, will result in changes to corn production, a major food staple in the United States. The objective of this study was to use the CERES-Maize model to evaluate potential changes in corn yield and water use under 2050 climate scenarios in the USDA-Economic Research Service (ERS) Heartland Region of the United States. CERES-Maize was used to simulate corn physiology and yields using weather data for three future climate scenarios generated by the ECHAM5 climate change models. The projected physiology and yield results were then compared to baseline conditions from the years 1997 through 2007. Throughout all future climate scenarios the number of days to corn silking and maturity were decreased under both rainfed and irrigated scenarios. Overall, the CERES-Maize model predicted increased total yields for the ERS-Heartland Region. However, large regional variability was observed throughout the Heartland Region, with yield simulations for the eastern production areas, including Ohio, Illinois, and Missouri, as well as southern Minnesota resulting in predicted declines in corn yields.

1. Introduction

The impacts of climate change from greenhouse gas emissions include the near-surface warming of terrestrial ecosystems, which is likely to have significant effects on the earth's hydrologic cycle (Barnett et al., 2005). Potential changes in the distribution and intensity of precipitation could increase the local impacts of water scarcity (Farre and Faci, 2006). This trend could have dire consequences for global agriculture, which is one of the largest consumers of the world's freshwater resources, and can account for up to 80% of the total diverted water usage in arid and semi-arid regions (Fereres and Soriano, 2006). In addition to the potential for local changes in water distribution due to climate change, water demands are predicted to increase sharply in the coming decades (Farre and Faci, 2006). As human populations increase, and more people gain access to water and sewer treatment facilities, regional water withdrawals will increase dramatically. While the actual amount of water on the planet will not decrease as a result of climate change (changes in global water volumes only occur on geologic time scales), the quality and available quantity of water will be lessened as global water withdrawals increase (Oki and Kanae, 2006). This could result in an increase in regional water scarcity, which would impact agricultural production (Fereres and Soriano, 2006).

The potential impact of climate change on the hydrologic cycle has been the subject of investigation in recent years (Leibowitz et al., 2014; Oni et al., 2014; Ryan et al., 2014). The most common predictions include increased intensity and frequency of extreme

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http://dx.doi.org/10.1016/j.ecoleng.2015.05.021
0925-8574/

hydrologic events such as droughts and floods (Huntington, 2006). The impacts of these events can be devastating for agriculture. Short-term spikes in temperature can significantly decrease productivity. One to two days of extreme temperatures during a sensitive growth stage for a crop can be damaging to agricultural operations (Mearns et al., 1984). In addition to the sensitivity of crops to sudden increases in temperature, historically, periods of abnormally low precipitation have resulted in the most dramatic reductions in crop productivity (Gornall et al., 2010). Competition for water from other human activities (urban and industrial demands) can lead to significant deficits in the amount of water available for irrigation within a basin (Vorosmarty et al., 2000). The competition for water resources between different sectors is likely to become more evident as climate change progresses (Scheffran and Battaglini, 2010). Given the potential threats that climate change poses to agricultural operations, it is important to consider future irrigation scenarios under water scarce conditions. It is likely that in the future deficit irrigation will become the norm in agricultural production (Farre and Faci, 2006; Fereres and Soriano, 2006).

These trends are particularly troubling when considering the potential impacts of climate change on the production of key food crops such as corn. The Food and Agriculture Organization of the United Nations (FAO) estimated that 40% the world's corn production was grown in the United States (Karlen et al., 2012). Corn for grain was the largest field crop produced in the United States in 2013, with approximately 13.9 bushels of corn harvested in that year. Of the 87.7 million acres harvested, over 13 million acres were irrigated, making corn the most irrigated crop in the United States (NASS, 2007; Irwin et al., 2014). Corn's importance in the US economy makes its management a top priority. One of the greatest emerging issues for corn production is the ability of the United States to not only sustain corn production at current levels, but to continue to maximize corn yields while maintaining agricultural integrity. For this reason, it is important for industry stakeholders and policymakers to anticipate the impacts of climate change. Growth models can be a useful tool to aid decision makers in projecting changes in corn production under future climate scenarios.

The objective of this study was to simulate corn yield and water demand using a regionally calibrated CERES-Maize model with projected weather data for climate scenarios for 2050 in order to determine the potential impacts of climate change on the physiological development and yield of corn produced in the Heartland Region of the United States (Fig. 1). The volume of water required to mitigate any adverse yield effects from climate change was estimated for the region. The objectives of this study were to predict the potential impacts of climate change on corn anthesis dates, maturity dates, and overall corn yield in 2050 under three climate change scenarios.

2. Materials and methods

For the purposes of this study, the CERES-Maize model was used to simulate corn production in the USDA Economic Research Service (ERS) Farm Resource Region 1 (36.042°N–46.625°N and 99.292°W–82.125°W), also known as the Heartland Region (ERS, 2000). (Jones and Kiniry, 1986). The CERES-Maize model has been improved since its development, and is now included in the software package DSSAT-CSM, the Decision Support System for Agrotechnology Transfer Crop Simulation Model (Jones et al., 2003; Hoogenboom et al., 2004). The CERES-Maize crop model is a dynamic simulation model that operates on a daily time step to predict crop growth in response to weather, soil, and management strategies. The model simulates phenological development, biomass accumulation, and partition, and yield in a variety of environments, and scenarios (Jones and Kiniry, 1986). Actual plant evapotranspiration, described as water use for this article, was determined using the Priestly–Taylor method.

2.1. Model inputs

The CERES-Maize model simulates corn physiology at a daily time step based on management practices, soil characteristics, and daily weather conditions. In this study, weather input data were obtained from the NASA Agroclimatology Archive, which is a subset of NASA's Prediction of Worldwide Energy Resource (POWER) project (NASA POWER, 2010). The parameters contained in this dataset are based on solar radiation data derived from satellite observations and meteorological data from the Goddard Earth Observing System assimilation model. The archive is globally comprehensive at 1° resolution, with dates ranging from 1983 to 2012. Parameters selected from this archive included daily estimates of insolation on a horizontal surface, daily mean, maximum, and minimum temperatures at 2 m above the ground surface, and precipitation (NASA POWER, 2010).

Soil inputs were derived from the International Soil Reference and Information Centre (ISRIC) World Inventory of Soil Emission

Fig. 1. The USDA economic research service (ERS) farm resource regions Modified from (Hoppe and Banker, 2010).