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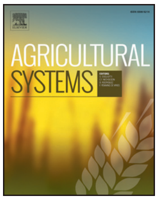

Projecting corn and soybeans yields under climate change in a Corn Belt watershed

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ABSTRACT

Climate change may have positive or negative effects on agricultural yields depending on location and mitigation and adaptation practices. This research investigates future corn and soybean yields in the Raccoon watershed, in the US Corn Belt, using projected climate data. We used the Environmental Policy Integrated Climate (EPIC) model to estimate the impact of climate change for 2015–2099 with data downscaled from eight atmosphere-ocean general circulation models (AOGCMs) with three emissions pathways reflecting low, medium and high greenhouse gas emissions scenarios. Soil properties were gathered from the Soil Survey Geographic Database and data on crop rotations was derived from CropScape, a geospatial cropland data layer product of the US National Agricultural Statistics Service (NASS). Our findings indicate that 20-year mean yields of both corn and soybean for 2080–2099 simulated in EPIC using all eight AOGCMs under low and medium carbon scenarios will increase in comparison to the 20-year mean yields for 2015–2034. However, under the high carbon scenario, 20-year means of both corn and soybean yields for 2080–2099 will decline in comparison to the 20-year mean yields for 2015–2034, pointing to the effects of climate change. We also examined the possible impact of carbon fertilization on yields. Our results show that carbon fertilization of soybean, a C_3 plant, may contribute to an increase in yield of 2% to 20% while its contribution to the growth of corn, a C_4 plant, will be much lower.

1. Introduction

Agricultural crops are grown in a variety of regions with diverse climatic conditions, their success depending on many factors such as soil quality, fertilizers, and seed technology and quality (Adams et al., 1998; Reddy and Hodges, 2000). As climate plays a determining role in agriculture, climate change may adversely affect global agricultural productivity, though some areas and crops may benefit from the change (Challinor et al., 2009; Li et al., 2011; Niu et al., 2009; Southworth et al., 2000). The net effect of climate change on agricultural productivity and the environmental impacts of agricultural activities will depend on the possible alteration of many properties of the climate and weather, such as the length of the growing season, water availability, rate of carbon fertilization, and the effects of weeds, insects and diseases among other factors (Bayer et al., 2015; Desjardins et al., 2007; Reilly et al., 2003; Wang et al., 2014). A number of crop simulation models are now being widely used to incorporate the impact of climate change on various ecosystem services together with the biophysical aspects of crops (Adams et al., 1998; Bryant et al., 2000; Challinor et al., 2009; Rosenzweig and Parry, 1994; Roudier et al., 2011). Although many modeling approaches have been attempted to simulate yields using climate projections derived from coupled atmosphere-ocean general circulation models (AOGCMs), fewer researchers have used downscaled data to estimate impacts on agricultural yields over a watershed. The use of downscaled data, coupled with high-resolution land use and soil data, can help policy makers and land managers better understand spatial and temporal impacts of climate change on yields. Fine-grained impact assessments are also important in understanding reactive individual adaptations, which are widespread in agriculture, and their spatial patterns. For example, differential yield impacts on C_4 and C_3 plants may affect crop profitability and alter farmers' crop choices. Here, we present a systematic approach to projecting agricultural yields under various climate scenarios by integrating the Environment Policy Integrated Climate (EPIC) model with field level data and downscaled 21st century climate data. The novelty of this approach is that it combines very detailed land use and soil data with downscaled climate scenarios. Therefore, it provides a much richer set of results than models relying on coarser spatial resolutions, which may underestimate effects on soils at the tails of the distribution. Since the results are spatially explicit, they can also be useful in outreach activities with farmers, and can be linked with watershed level water quantity and quality models.

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Climate change may have different impacts on plants depending on climate zones and types of plants. A number of researchers have indicated that agriculture may benefit from climate change, particularly in the temperate zone, due to increased CO_2 concentrations in the atmosphere, a phenomenon termed the carbon fertilization effect (Heimann and Reichstein, 2008; McGrath and Lobell, 2013). It has also been predicted that the southern hemisphere may suffer more adverse consequences of climate change than the northern hemisphere due to differences in carbon concentrations in the atmosphere. Carbon fertilizer effects are different for C_3 and C_4 plants. The productivity gain is generally greater for plants with the C_3 photosynthetic pathway compared to plants with the C_4 pathway (Adams et al., 1998; Kimball et al., 2002; Long et al., 2005; Rosenzweig and Iglesias, 1998; Thomson et al., 2005). Therefore, given crop production patterns, climate change may have more effects on C_3 plants than C_4 plants. This could affect global food security as many plants that are sources of staple foods in developing countries in the southern hemisphere such as wheat, rice, and beans are C_3 plants. This may create upward pressure on intensive agriculture in the northern hemisphere if demand for food grains were to grow. Hence, the inclusion of carbon fertilization effects on C_3 and C_4 plants in our research provides insights for future mitigation and adaptation endeavors at the watershed scale, where more interaction and outreach with farmers occur, but our results can be contextualized at a global scale as well.

2. Materials and methods

2.1. Selection of crops and study area

Since agricultural production involves thousands of crops and practices worldwide, to reduce the simulations to a manageable size, a set of representative crops and an appropriate study area were chosen. Corn and soybeans were selected for the study as these two crops combined cover almost 53% of the United States' total agricultural land (USDA NASS, 2016). Among U.S. states, Iowa is the largest producer of corn and ethanol and one of the largest producers of soybeans (USDA NASS, 2016). Within Iowa, the Raccoon watershed was chosen as a representative region of the US Corn Belt because of its highly productive and intensive agriculture.

2.2. Description of the EPIC model

The EPIC model (version 0509) was used to simulate the yield response of corn and soybeans to various climate change scenarios. The EPIC model simulates both the impact of climate change on specific crops and on the environmental indicators associated with the crop's production, including a host of characteristics such as soil quality, weather parameters, management practices and landscape type (Izaurralde et al., 2006; Williams et al., 1984; Williams et al., 1983). EPIC calculates plant biomass by simulating carbon fixation through photosynthesis and respiration for maintenance and growth (Stockle et al., 1992). The model can estimate the effects of climate, soil and management decisions on soil, water, nutrients and pesticides and then predict their accumulated impacts in terms of variables such as yields, SOC (Soil Organic Carbon), soil erosion and water quality (Izaurralde et al., 2006; Williams et al., 1984; Williams et al., 1983). EPIC is an extensively tested model (Izaurralde et al., 2006; Williams et al., 1984). Researchers in the US and all over the world have used this model for various types of simulations, and the model has been successfully validated (Balkovič et al., 2013; Causarano et al., 2008; Chavas et al., 2009; Chung et al., 1999; Izaurralde et al., 2006). EPIC has been also used to research climate change impacts on several crops worldwide (Dhakhwa et al., 1997; Liu et al., 2007; Priya and Shibasaki, 2001; Tingem and Rivington, 2009).

2.3. Development of baseline field data

We used CropScape, an online visualization portal of the National Agricultural Statistics Service (NASS) of the United States Department of Agriculture (USDA), to generate historical Geospatial Cropland Data Layers (CDL) for the Raccoon Watershed to identify field data with an appropriate geo-reference to soil data and management practices (USDA NASS Research and Development Division, 2016). The data was then processed in an ArcGIS environment to identify land use land cover (LULC) for multiple years. This procedure enabled us to identify a total of 2481 unique land use areas (ULUAs) including crop fields, forests, pastures, and urban areas in the Raccoon Watershed (Teshager et al., 2016). These ULUAs were then processed to identify their soils. Out of 2481 ULUAs, 2045 spatially explicit crop fields were identified together with their geo-references to soil map units. Similarly, crop rotations for each field for the three years between 2008 and 2010 were also identified using the procedure. We used four crop rotation choices: i) Corn-Soybean-Corn (CSC), ii) Corn-Corn-Soybean or Soybean-Soybean-Corn (CCS or SSC), iii) continuous Corn (CC) and iv) others, that include pastures, forests, urban areas and water. According to the results of the ArcGIS processing procedure, 56% of the Raccoon Watershed was under the CSC rotation, 19% was under CCS or SSC, 10% was under CC, and 15% was under “others”, as shown in Fig. 1.

In general, three main tillage categories are practiced in US agriculture: conventional, conservation and no-till (Horowitz et al., 2010). The conventional tillage system leaves less than 15% crop residue on the ground. The system involves often multiple operations with implements such as mold board, disk and/or chisel plow. Conservation tillage systems are methods of soil tilling which leave a minimum of 30% of crop residue on the soil surface so as to reduce soil erosion. Soil loss through water erosion is greatly reduced when crop residue is left on the soil surface and soil drainage, organic matter, and moisture content are improved. Conservation tillage also reduces air pollution, sequesters carbon, improves water quality and creates wildlife habitat. No-till is a subcategory of conservation tillage in which plows, disk etc. are never

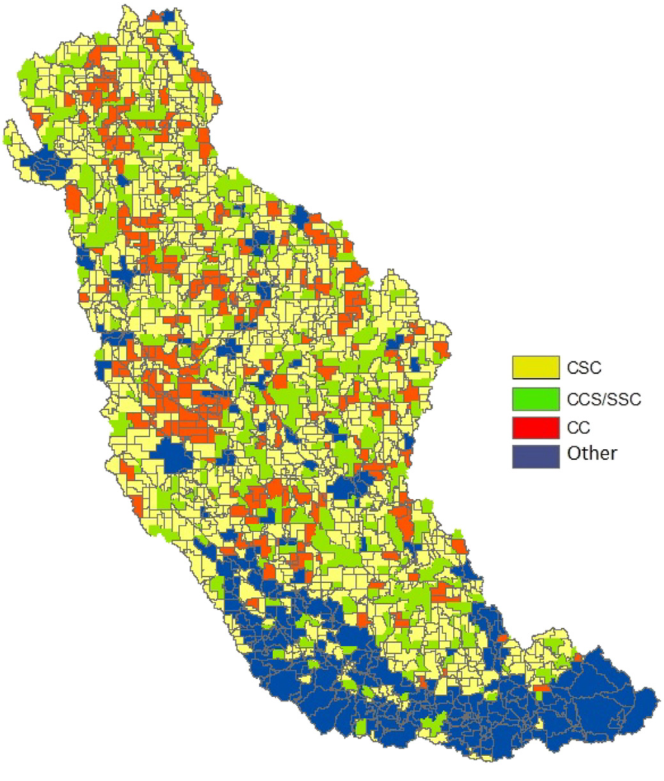

Fig. 1. Distribution of crop rotation practices in the Raccoon Watershed for 2008–2010.