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Responses of crop yield and water use efficiency to climate change in the North China Plain

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ABSTRACT

Based on future climate change projections offered by IPCC, the responses of yields and water use efficiencies of wheat and maize to climate change scenarios are explored over the North China Plain. The climate change projections of 21st century under A2A, B2A and A1B are from HadCM3 global climate model.

A climate generator (CLIGEN) is applied to generate daily weather data of selected stations and then the data is used to drive CERES-Wheat and Maize models. The impacts of increased temperature and CO_2 on wheat and maize yields are inconsistent. Under the same scenario, wheat yield ascended due to climatic warming, but the maize yield descended. As a more probable scenario, climate change under B2A is moderate relative to A2A and A1B. Under B2A in 2090s, average wheat yield and maize yield will respectively increase 9.8% and 3.2% without CO_2 fertilization in this region. High temperature not only affects crop yields, but also has positive effect on water use efficiencies, mainly ascribing to the evapotranspiration intensification. There is a positive effect of CO_2 enrichment on yield and water use efficiency. If atmospheric CO_2 concentration reaches nearly 600 ppm, wheat and maize yields will increase 38% and 12% and water use efficiencies will improve 40% and 25% respectively, in comparison to those without CO_2 fertilization. However, the uncertainty of crop yield is considerable under future climate change scenarios and whether the CO_2 fertilization may be realized is still needed further research.

1. Introduction

Climate change may have important impacts on agriculture. Based on the simulation of GCMS, future changes of global average temperature are expected to be between 2 °C and 4.5 °C in this century (IPCC, 2001), and some regional areas would be even warmer than the global average (Giorgi and Bi, 2005). So, both for policymakers and scientists, impacts of global warming on agriculture and water resources are referred to as an important issue (Gregory and Ingram, 2000; Sanchez, 2000; Fuhrer, 2003).

Under climate warming, and CO_2 concentration increasing as well, the crop production could be affected in several ways. The environment changes including soil conditions (mainly changes of soil moisture) and air conditions could strongly affect the physiological processes such as photosynthesis, respiration and partitioning of photosynthesis production (Chartzoulakis and Psarras, 2005; Yang and Zhang, 2006). Along with the mean temperature increasing, the occurring frequency of extreme temperature may increase, that may abruptly affect the crop activity (Körner et al., 2002; Wu et al., 2006). Effects of higher temperature, elevated CO_2 concentration and changed precipitation are complicated (Dhungana et al., 2006; Walker and Schulze, 2008). However, CO_2 fertilization will alleviate the effects of temperature and precipitation on crop yield (Brown et al., 2000; Krishnan et al., 2007; Ludwig and Asseng, 2006). Increment of atmospheric CO_2 had an obvious positive effect on photosynthetic rates, leading to enhancement of total biomass and yield of C3 crops (Dhakhwa et al., 1997; Wolf et al., 2002; de Costa et al., 2006). With the physiological process's changes, the management practices could be affected through changes of water use (irrigation) and agricultural inputs such as herbicides, insecticides and fertilizers.

The impact of future climate change on crop production has been widely studied by using crop models and climate change scenarios (Challinor et al., 2005; Hussain and Mudasser, 2007; Challinor and Wheeler, 2008; Tao et al., 2008). Future climate scenarios may be beneficial for wheat in some regions, but could reduce productivity in zones where optimal temperatures already

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exist (Ortiz et al., 2008). The tendency of wheat yield in American Northern Plains will increase 25% in 2030 and 36% in 2095 (Izaurralde et al., 2003). Furthermore, winter wheat production in southern Sweden had the same tendency, being predicted to increase by 10–20% in 2050 (Eckersten et al., 2001). However, wheat yield in southern Australia will decrease about from 13.5% to 32% under most climate change scenarios (Luo et al., 2005).

Rainfed maize yield is vulnerable to climate change, especially in dry regions (Mati, 2000; Jones and Thornton, 2003; Abraha and Savage, 2006). Maize yield in American Corn Belt will increase about 17% in 2095, but that in Northern Plains and Southern Plains will decrease about 9% and 6% (Izaurralde et al., 2003). However, the increment of maize yield on Loess Plateau of China was obviously higher than other regions, which are 57% for A2A and 54% for B2A during 2070–2099 with conventional tillage (Zhang and Liu, 2005).

The potential impact of climate change on agriculture is impressible in semi-humid and semi-arid region (Thomson et al., 2006; Tao et al., 2003). The North China Plain (NCP) locates in the semi-humid region and is vulnerable to climate change (Lin, 1996). The North China Plain as the main food supply area contributes approximately 41% of the total wheat yield and more than 30% of the total maize yield in China. In future, evapotranspiration and water use efficiency of crop will alter with climate change (Thomas, 2008; Mo et al., 2007). To adapt crop systems to the changing climate, it is important to know how climate change affects agricultural production and water use efficiency.

The aim of this paper is to explore the responses of winter wheat and summer maize yields and water use efficiencies to climate change with the DSSAT CERES model. Climate change projections of A2A, B2A and A1B are from HadCM3 model. The Climate Generator (CLIGEN) is used to create daily weather series with monthly projection data. The uncertainties of crop yield responses are also explored.

2. Methods and materials

2.1. Study region

The North China Plain locates in the north of China (31°24′N to 42°42′N, and 110°18′E to 122°42′E) (Fig. 1), with a warm and semi-humid continental monsoon climate. The mean annual temperature of the plain is 8–15 °C. Winter is cold and dry, whereas summer is hot and wet. The mean annual precipitation is 600–800 mm. The main agricultural system is winter wheat and summer maize rotation cropping. Planting areas of wheat and maize in the North China Plain occupy about 45% and 33% of total planting area in China. Average yields of wheat and maize are 4500 kg ha^{-1} and 5300 kg ha^{-1} in this region, respectively. Growth period of winter wheat is from October to next June and that of summer maize is from June to September. The growth period length of wheat and maize are about 250 days and 100 days, respectively. Agricultural soil is mainly calcareous and alluvial soil in most regions, but partly yellow and brown soil. Nice soil texture supplies advantaged condition for high crop production. The water demand of winter wheat is far beyond the precipitation during wheat growing, so it is necessary to irrigate. During maize growing, there is no irrigation, because the need of evapotranspiration can be satisfied by rainfall. Seven sites (Beijing, Shijiazhuang, Anyang, Jinan, Zhengzhou, Xinyang, Xuzhou) were selected to reflect spatial variability in this study.

2.2. Materials introduction

The DSSAT CERES crop model and the Climate Generator model (CLIGEN) are chosen in this paper. The former is mainly used to simulate the crop growth process and water balance and the later is used to generate the weather data to drive the crop model. In a CERES model, the soil data, weather data under baseline and under climate change projections, crop genetic parameters and crop management data are needed as the input data. By running CERES-Wheat and CERES-Maize model, the yield, biomass and evapotranspiration of wheat and maize will be obtained.

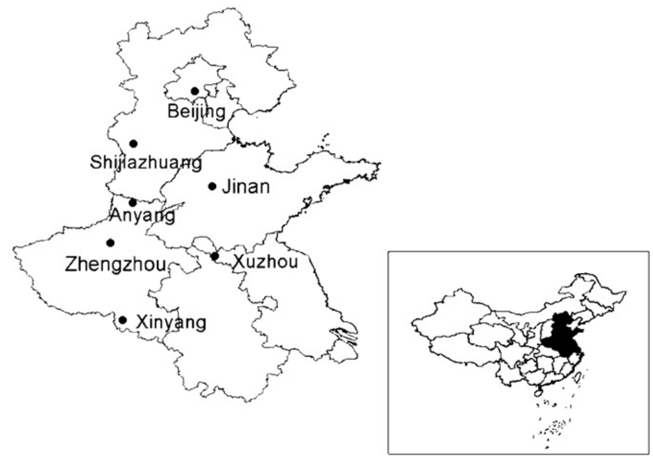

Fig. 1. The locations of the seven selected sites over the North China Plain.

CLIGEN model as the stochastic weather generator researches the general characters of weather and climate and simulates daily weather data based on the statistics of historical climate. Based on the probability of dry and wet, range of temperature change and solar radiation of history climate data, CLIGEN takes monthly weather data as input, and then generates precipitation, daily maximum temperature, minimum temperature and solar radiation.

2.3. DSSAT CERES model description

DSSAT CERES4.0 (Crop Estimation through Resource and Environment Synthesis) is a model based on the crop growth module in which crop growth and development are controlled by phenological development processes. The DSSAT model contains the soil water, soil dynamic, soil temperature, soil nitrogen and carbon, individual plant growth module (including CERES-Maize and CERES-Wheat models) and crop management module (including planting, harvesting, irrigation, fertilizer and residue modules). This model is not only used to simulate the crop yield, but also be used to explore the effect of climate change on agriculture productivity and irrigated water (Alexandrov and Hoogenboom, 2001). For example, by setting a certain management method, the responses of yield to temperature and CO_2 concentration can be studied (Tubiello and Fischer, 2007).

2.4. Data processing

The soil data are obtained from the soil database of China (http://www.soil.csdb.cn), which includes the soil physical characteristics in different layers, containing bulk density, organic carbon concentration and fractions of sand, silt and clay. Climatic

Table 1
CO_2 concentrations under future climate projections in three periods (ppm).

	A2A	B2A	A1B
2030s	488	445	479
2060s	632	521	588
2090s	775	597	697