Agriculture, Ecosystems and Environment 196 (2014) 51–58

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Divergence of climate impacts on maize yield in Northeast China

Xuhui Wang, Liqing Peng, Xinping Zhang, Guodong Yin, Chuang Zhao, Shilong Piao *

College of Urban and Environmental Sciences, Peking University, Beijing 100871, China

ARTICLE INFO

Article history:
Received 18 December 2013
Received in revised form 7 June 2014
Accepted 15 June 2014
Available online 5 July 2014

Keywords:
Maize yield
Asymmetric climate impacts
Day-time temperature
Night-time temperature
Northeast China

ABSTRACT

Northeast China (NEC), the most productive maize growing area in China, has experienced pronounced climate change. However, the impacts of historical climate changes on maize production and their spatial variations remain uncertain. In this study, we used yield statistics at prefecture scale over the past three decades, along with contemporary climate data, to explore the yield–climate relationship and its spatial variations. At the regional scale, maximum and minimum temperature changes had opposite impacts on maize yield, which increased by 10.0 ± 7.7% in response to a 1 °C increase in growing season mean daily minimum temperature (T_{min}), but decreased by 13.4 ± 7.1% in response to a 1 °C increase in growing season mean daily maximum temperature (T_{max}). Variations in precipitation seemed to have small impacts on the maize yield variations (−0.9 ± 5.2%/100 mm). However, these responses of maize yield to climate variations were subject to large spatial differences in terms of both the sign and the magnitude. ~30% of the prefectures showed a positive response of maize yield to rising T_{max}, which was in contrast to the negative response at the regional scale. Our results further indicate that the spatial variations in the yield response to climate change can be partly explained by variations in local climate conditions. The growing season mean temperature was significantly correlated with the response of maize yield to T_{max} ($R = -0.67$, $P < 0.01$), which changes from positive to negative when the growing season mean temperature exceeds 17.9 ± 0.2 °C. Precipitation became the dominant climatic factor driving maize yield variations when growing season precipitation was lower than ~400 mm, but had a weaker influence than temperature over most of the study area. We conclude that, although NEC is a region spanning only more than one millions of kilometer squares, the divergence of the yield response to climatic variations highlights the need to analyze the yield–climate relationship at fine spatial scales.

1. Introduction

Understanding how climate change has been affecting crop production is a prerequisite to ensure global food security and to inform adaptation decisions (IPCC, 2007; Schmidhuber and Tubiello, 2007; Godfray, 2011). Both modeling and empirical studies have indicated that maize yield is negatively affected by climate change at the global scale (IPCC, 2007; Lobell et al., 2011). However, global analyses could have hidden regional winners and losers (Godfray et al., 2010). Detailed regional analyses are thus required to explore possible mechanisms for the spatial differences in impacts of climate change on maize yield.

Maize is one of the staple food crops in China, which is currently the world's second largest maize producer (Meng et al., 2006). Although maize is cultivated in every province in China, the three provinces in Northeast China (NEC) alone account for more than 30% of China's maize production and 27% of its maize growing area (National Bureau of Statistics in China (NBSC), 2011). Part of this region is also the most productive maize growing area in China, known as the golden maize belt. Over the past decades, NEC has experienced faster warming than the lower latitudes of China, along with pronounced precipitation changes (Piao et al., 2010; Editorial Board of National Climate Change Assessment Report (EBNCCAR), 2011). Understanding how this historical climate change could have influenced maize production in NEC is thus critical to China's food production and to decisions on climate change mitigation.

A variety of approaches, including statistical analyses and crop models, have been used to explore the influence of climate change on maize production in NEC (e.g., Xiong et al., 2007; Tao et al., 2008; Chen et al., 2011; Liu et al., 2012; Zhang and Huang, 2012). The estimates of the response of maize yield to climate change are, however, largely uncertain as they differ even in their signs. Some modeling studies (Xiong et al., 2007; Liu et al., 2012) indicate that warming, in particular an increase in maximum temperature, could reduce maize yield in NEC. For example, simulations by Liu

* Corresponding author. Tel.: +86 10 6276 5578; fax: +86 10 6275 6560.
E-mail addresses: slpiao@pku.edu.cn, ShiLong.Piao@lsce.ipsl.fr (S. Piao).

http://dx.doi.org/10.1016/j.agee.2014.06.009
0167-8809/

et al. (2012) showed that a 1 °C warming in maximum temperature would reduce maize yield by 2–9% at different sites in NEC. On the contrary, another analysis indicated that 1 °C warming could improve maize yield by more than 20% in parts of NEC (Wang et al., 2007), which is in line with some other studies indicating warming has benefited maize yield in NEC (EBNCCAR, 2011; Chen et al., 2011). Consequently, more empirical evidence is still needed to reduce the uncertainties in diagnosing and predicting the response of maize yield to climate change.

Empirical yield–climate relationships are often explored with yield statistics at province, county or farm scale (e.g., Tao et al., 2008; Chen et al., 2011; Liu et al., 2012; Zhang and Huang, 2012). It was found that the response of crop yield to climate change is scale-dependent (Tao et al., 2008; Zhang et al., 2010). As the relationship between maize yield and climate at prefecture scale has not yet been explored, it is of need to fill this gap. Moreover, a prefecture in NEC usually spans a relatively homogeneous geographic area from ∼5000 to ∼54,000 km^2, covering a few grids of the high-resolution gridded climate dataset (Mitchell and Jones, 2005). The match of scale in statistics and climate data makes it suitable to explore yield–climate relationship. In addition to the scale issue, previous studies show large spatial variations in the response of crop yield to climate change (e.g., Tao et al., 2008; Chen et al., 2011), but these differences often remain unexplained or qualitatively attributed to regional differences in crop management, soils, crop varieties and other factors (e.g., Tao et al., 2008; Lobell et al., 2008). Hence, in this study, we analyzed both the yield–climate relationship and its spatial variations over 36 prefectures in NEC during 1980–2009. The objectives of this study were (1) to understand how maize yield, at regional and prefecture scale, has responded to historical climate change over the past three decades, and (2) to explore whether spatial variations in these responses can be explained by differences in local climate conditions.

2. Datasets and methods

2.1. Study area

Northeast China (NEC) is located in northernmost China (38°N–54°N) (Fig. 1). It has a cool summer (mean June–August temperature 20 °C) and long winter (five months), which results in a short thermal growing season (May–September) that only allows single cropping. As Fig. 2a shows, the mean growing season temperature in maize planting areas generally follows a latitudinal gradient from 10 °C in the north to 22 °C in the south, except for some high-altitude mountainous areas (Daxing'anling, Xiaoxing'anling and Changbai mountain ranges) which are cooler than other regions on the same latitude. The growing season precipitation exhibits a southeast–northwest gradient, decreasing from more than 800 mm to less than 400 mm (Fig. 2b).

The prefecture is a mid-level administration that is part of a province and containing several counties. The NEC is comprised of 36 prefectures with their area ranging from 4.8×10^3 km^2 (Liaoyang) to 5.44×10^4 km^2 (Heihe).

Maize is widely cultivated in NEC (Fig. 2c). The total maize growing area is about 6 million hectares. The average yield is about 5000 kg/ha, ranging from 3575 to 9051 kg/ha among different prefectures with warmer area tending to have larger yield (Fig. S2). The most productive area concentrated in Songliao Plain (Fig. 2d). More than 90% of the maize fields over this region is rainfed (NBSC, 2011), with average precipitation more than 300 mm during the maize growing season (Fig. S2).

2.2. Datasets

Yield statistics for each prefecture area and in each province were obtained from the Agricultural Yearbook (1980–2009) of Liaoning Province, Jilin Province, and Heilongjiang Province, the three provinces comprising NEC (Fig. S1), accessed from http://data.cnki.net. It should be noted that prefecture-level statistics for Heilongjiang during 1980–1985 and for Liaoning during 1980–1991 are not available from the database.

Monthly temperature and precipitation data during 1980–2009 were obtained from the Climatic Research Unit (CRU, University of East Anglia), at a spatial resolution of 0.5 degrees (Mitchell and Jones, 2005). We defined the maize growing season as the period from May to September according to the typical cropping system in NEC (Meng et al., 2006). The maize growing area was obtained from the Maps of Cropland Distribution in China (Frolking et al., 2002), which has a spatial resolution of 0.5 degrees.

2.3. Analyses

For each prefecture area, growing season mean daily maximum temperature (T_{max}), growing season mean daily minimum temperature (T_{min}) and growing season precipitation (Pre) were calculated as the maize growing area weighted averages during May–September each year.

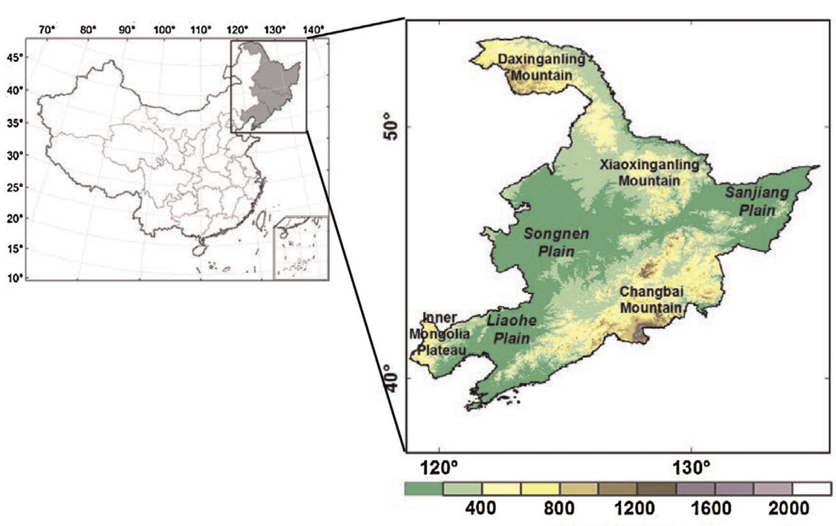

Fig. 1. Geographic location of Northeast China (NEC) and spatial distribution of the elevation over NEC.