Agricultural and Forest Meteorology 189–190 (2014) 91–104

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Responses of wheat growth and yield to climate change in different climate zones of China, 1981–2009

Fulu Tao[a,*], Zhao Zhang[b], Dengpan Xiao[a,c], Shuai Zhang[a], Reimund P. Rötter[d], Wenjiao Shi[a], Yujie Liu[a], Meng Wang[a,c], Fengshan Liu[a,c], He Zhang[a,c]

[a] Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing 100875, China
[c] University of Chinese Academy of Sciences, Beijing 100039, China
[d] MTT Agrifood Research Finland, Lönnrotinkatu 5, Mikkeli FI-50100, Finland

ARTICLE INFO

Article history:
Received 18 July 2013
Received in revised form
20 December 2013
Accepted 14 January 2014

Keywords:
Agriculture
Climate change
Crop
Impact and adaptation
Phenology
Yield

ABSTRACT

The experiment observations at 120 agricultural meteorological stations spanning from 1981 to 2009 across China were used to accelerate understandings of the response of wheat growth and productivity to climate change in different climate zones, with panel regression models. We found climate during wheat growth period had changed significantly during 1981–2009, and the change had caused measurable impacts on wheat growth and yield in most of the zones. Wheat anthesis date and maturity date advanced significantly, and the lengths of growth period before anthesis and whole growth period were significantly shortened, however the length of reproductive growth period was significantly prolonged despite of the negative impacts of temperature increase. The increasing adoption of cultivars with longer reproductive growth period offset the negative impacts of climate change and increased yield. Changes in temperature, precipitation and solar radiation in the past three decades jointly increased wheat yield in northern China by 0.9–12.9%, however reduced wheat yield in southern China by 1.2–10.2%, with a large spatial difference. Our studies better represented crop system dynamics using detailed phenological records, consequently better accounted for adaptations such as shifts in sowing date and crop cultivars photo-thermal traits when quantifying climate impacts on wheat yield. Our findings suggest the response of wheat growth and yield to climate change is underway in China. The changes in crop system dynamics and cultivars traits have to be sufficiently taken into account to improve the prediction of climate impacts and to plan adaptations for future.

1. Introduction

About 21% of the world's food depends on wheat crop, which grows on 200 million hectares of cropland worldwide (FAO, 2012). Global wheat demand, particularly in developing counties, will continue to increase in the near future (Ortiz et al., 2008). However climate change may negatively affect wheat yield in some major wheat production regions of the world (Ortiz et al., 2008; Challinor et al., 2010; Asseng et al., 2011; Olesen et al., 2011; Lobell et al., 2011, 2012; Licker et al., 2013), although the impacts have large uncertainties and remain inconclusive in terms of mechanisms, magnitude and spatial pattern (Ortiz et al., 2008; Asseng et al., 2013; Tao and Zhang, 2013).

Since 1980s, China has continued to hold the greatest share of world wheat production, averaging 112 Mt from 2006 to 2010 (FAO, 2012). The impact of climate change/variability on wheat growth and productivity in China has been of key concern (Tao et al., 2006, 2008, 2012a; Xiong et al., 2008; You et al., 2009; Challinor et al., 2010; Tao and Zhang, 2013). Previous studies have tried to project long-term climate change on wheat productivity in future using crop models, driven by climate change scenarios output from global climate model or regional climate model (Xiong et al., 2008; Challinor et al., 2010; Liu and Tao, 2013; Tao and Zhang, 2013). Recently, a number of studies have also tried to investigate climate impacts on wheat yield in the past few decades based on reported harvest yield using statistical approaches (Tao et al., 2008, 2012; You et al., 2009; Zhang and Huang, 2013). Most of the statistical studies correlate crop yields at a province or county scale from census data with seasonal climate computed during a coarse and fixed crop growth period. In fact, cropping systems have shifted in the past few decades under the combined effects of climate change, cultivars turnover and agronomic management (Welch et al., 2010; Tao et al., 2012a,b; Tao and Zhang, 2013). There is a clear and present need to synthesize crop yield and climate data from

* Corresponding author. Tel.: +86 1064888269.
E-mail address: taofl@igsnrr.ac.cn (F. Tao).

0168-1923/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agrformet.2014.01.013

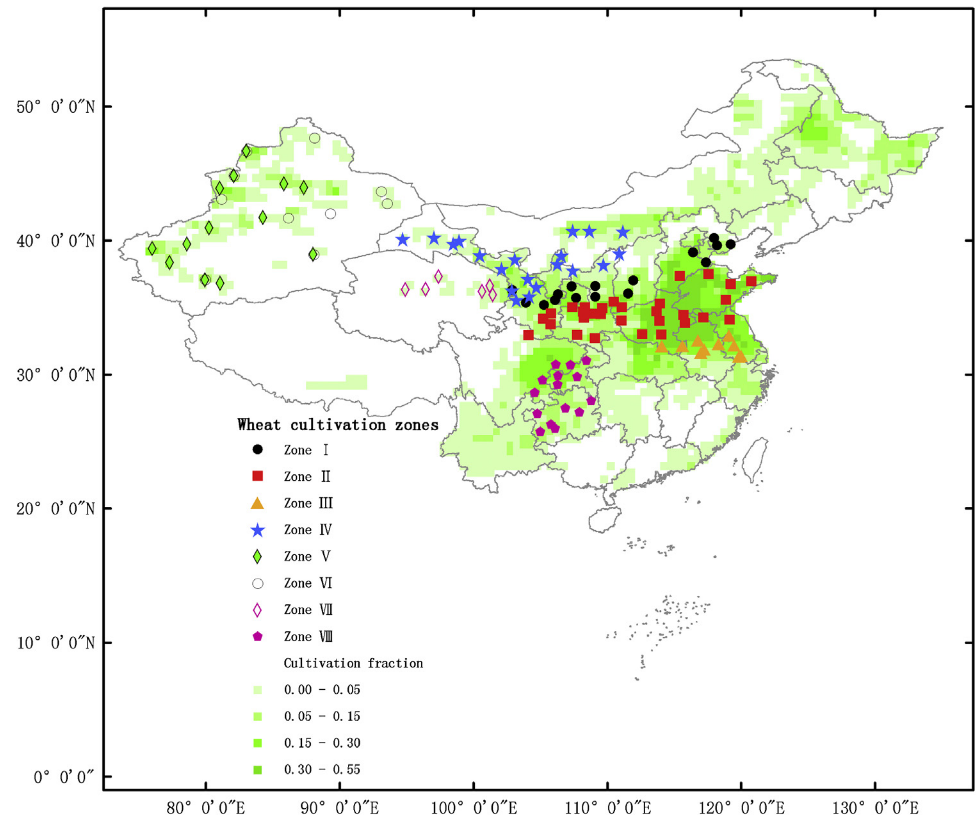

Fig. 1. Wheat cultivation fraction and major production zones of China, as well as the agricultural meteorological stations in the major production zones used in the study. The wheat cultivation fractions were based on Qiu et al. (2003).

different areas, with more detailed information on crop system and management, to look insights into the response mechanisms of crop growth and productivity to climate change (Lobell and Asner, 2003; Tao et al., 2006; Tao and Zhang, 2013; Welch et al., 2010; Lobell et al., 2011). Such studies can provide observed evidences to improve the projections of climate impacts on future food production and to design adaptations (Lobell and Asner, 2003; Tao et al., 2012b).

In the present study, the experiment observations at 120 agricultural meteorological stations (Fig. 1, Table 1) spanning from 1981 to 2009 across China were used to accelerate understandings of the response and adaptation of wheat growth and productivity to climate change in different climate zones. The long-term detailed experiment records on cultivars, major phenological dates, yields and management practices in each year provide us a unique opportunity to look insight into the dynamics of crop systems in response to climate change in the past three decades. We aim to understand in the past three decades (1) how climate during wheat growth period has changed? (2) how wheat phenology and crop system dynamics has changed in response to climate change? and (3) to what extent the climate change has affected wheat growth and productivity in a setting in which farmers make decisions based on the weather they observe every day, across the major wheat production regions of China (Fig. 1)?

2. Materials and methods

2.1. Stations and data

The study areas include the major wheat production regions in China. According to wheat cultivation zones in China (Jin, 1961; Zhao, 2010), the agricultural meteorological stations were grouped into eight zones, i.e., Zone I, Zone II, Zone III, Zone IV, Zone V, Zone VI, Zone VII and Zone VIII (Fig. 1). These zones were created to reflect differences in biophysical conditions such as soil and climate and cropping system (Jin, 1961; Tong, 1992; Zhao, 2010).

Wheat trial data on wheat cultivars, phenology, yields and management practices from 1981 to 2009 were from China agricultural meteorological experiment stations, which are maintained by China Meteorological Administration (CMA). The detailed

Table 1
General information on wheat type, emergence date, anthesis date and maturity date in major wheat production zones of China. The data were based the observations between 1981 and 2009 at the agricultural experiment stations used in the study.

Wheat cultivation zones	Wheat type	Number of stations	Emergence date	Anthesis date	Maturity date
Zone I	Winter wheat	16	Oct 5th	May 15th	Jun 20th
Zone II	Winter wheat	30	Oct 20th	May 2nd	Jun 5th
Zone III	Winter wheat	10	Nov 5th	Apr 25th	May 30th
Zone IV	Spring wheat	20	Apr 10th	Jun 13th	Jul 17th
Zone V	Winter wheat	13	Oct 8th	May 16th	Jun 20th
Zone VI	Spring wheat	10	Apr 17th	Jun 12th	Jul 17th
Zone VII	Spring wheat	6	Apr 24th	Jul 9th	Aug 27th
Zone VIII	Winter wheat	15	Nov 11th	Apr 3rd	May 12th