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Wheat yield benefited from increases in minimum temperature in the Huang-Huai-Hai Plain of China in the past three decades

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ABSTRACT

Our understanding of climate impacts and adaptations on crop growth and productivity can be accelerated by analyzing historical data over the past few decades. We used crop trial and climate data from 1981 to 2009 at 34 national agro-meteorological stations in the Huang-Huai-Hai Plain (HHHP) of China to investigate the impacts of climate factors during different growth stages on the growth and yields of winter wheat, accounting for the adaptations such as shifts in sowing dates, cultivars, and agronomic management. Maximum (T_{max}) and minimum temperature (T_{min}) during the growth period of winter wheat increased significantly, by 0.4 and 0.6 °C/decade, respectively, from 1981 to 2009, while solar radiation decreased significantly by 0.2 MJ/m^2/day and precipitation did not change significantly. The trends in climate shifted wheat phenology significantly at 21 stations and affected wheat yields significantly at five stations. The impacts of T_{max} and T_{min} differed in different growth stages of winter wheat. Across the stations, during 1981–2009, wheat yields increased on average by 14.5% with increasing trends in T_{min} over the whole growth period, which reduced frost damage, however, decreased by 3.0% with the decreasing trends in solar radiation. Trends in T_{max} and precipitation had comparatively smaller impacts on wheat yields. From 1981 to 2009, climate trends were associated with a ≤30% (or ≤1.0% per year) wheat yield increase at 23 stations in eastern and southern parts of HHHP; however with a ≤30% (or ≤1.0% per year) reduction at 11 other stations, mainly in western part of HHHP. We also found that wheat reproductive growth duration increased due to shifts in cultivars and flowering date, and the duration was significantly and positively correlated with wheat yield. This study highlights the different impacts of T_{max} and T_{min} in different growth stages of winter wheat, as well as the importance of management (e.g. shift of sowing date) and cultivars shift in adapting to climate change in the major wheat production region.

1. Introduction

The potential impact of future climate change on agricultural production and food security has attracted considerable attention (e.g., Ortiz et al., 2008; Gornall et al., 2010; Lobell et al., 2011a, 2012; Müller et al., 2011; Porter et al., 2014). Many climate change impact studies make use of process-based crop models to assess consequences of future climate change for crop production or estimate the contribution of past climate changes to crop production. A process-based crop model has the strength of simulating the interactions between management and environmental conditions on the main processes of crop growth and development. Crop models have been routinely applied to assess the potential impacts of climate change on crop productivity since the late 1980s (White et al., 2011). However, the use of crop models for climate change impact studies is not without limitation. First, every crop model is a simplification of reality which takes some factors into account in greater detail than others. The assumptions and simplifications

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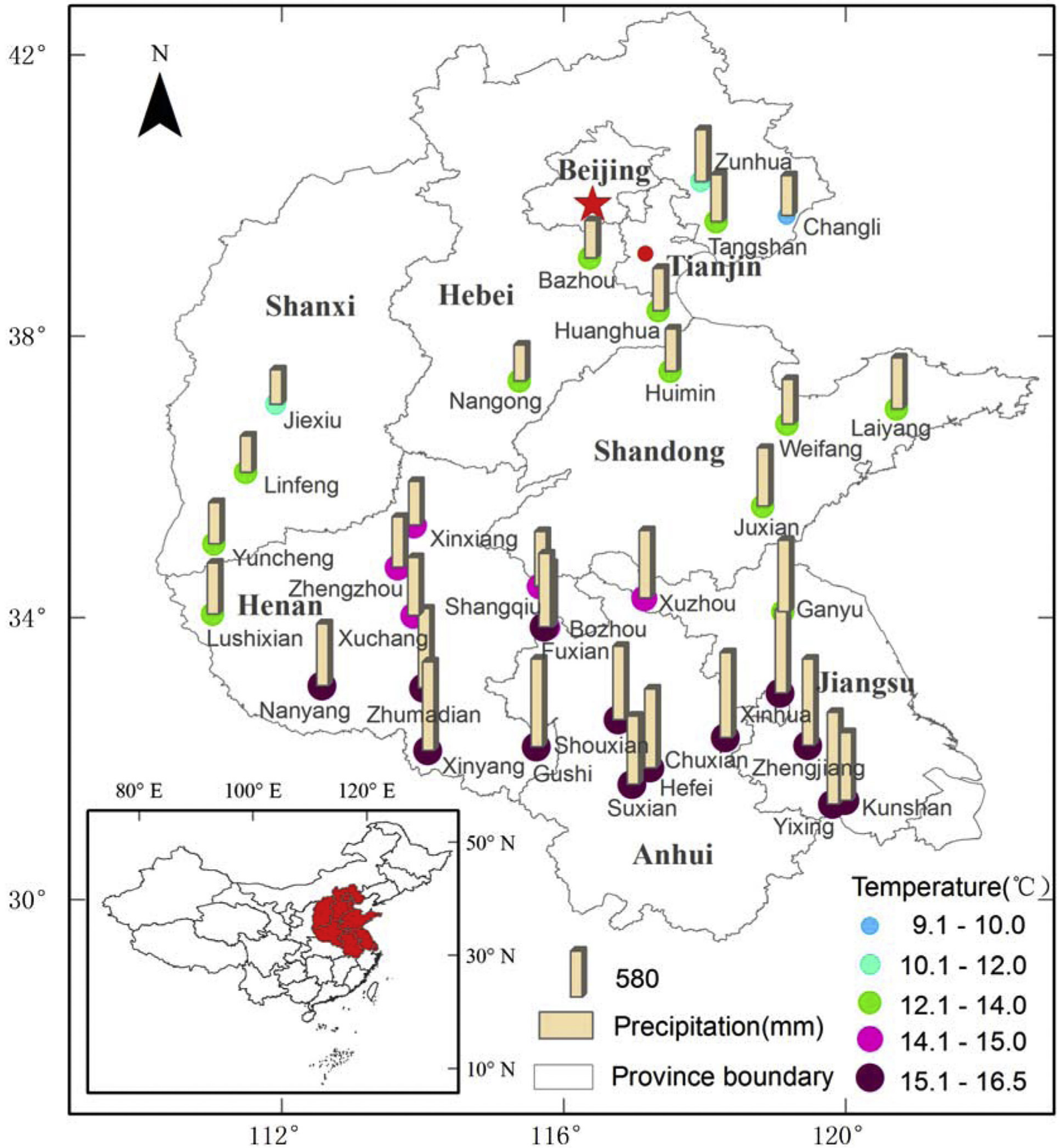

Fig. 1. The study region and the locations of the agro-meteorological experiment stations used in the study. Annual mean temperature and total precipitation during 1981–2009 at each station are also shown.

made in a crop model are necessarily affected by preferences and idiosyncrasies of the model developers, based on their understanding and synthesis of the available scientific evidence at a given time, and the aims and constraints during the model development. Furthermore, with few exceptions (e.g. Sacks and Kucharik 2011) climate impact studies with crop models do not account for changes in crop varieties and management practices over time (Liu et al., 2010; Reidsma et al., 2010; Rötter et al., 2011; Tao et al., 2012a). Finally, key factors affecting crop yield such as pests, pathogens, weeds, soil quality deficits, flooding, and heat damage are very difficult to account for. Therefore, climate change impact assessments, performed with process-based crop models, may not properly represent the required or possible adaptations to a changing climate. On the other hand, a statistical model can quantify crop yields' response to climate change and account for other factors according to the information available, but the true behavior of crop growth may be very difficult to capture as a statistical model lacks physiological structure (Lobell and Burke, 2010).

Our understanding on climate impacts and adaptations of crop growth and productivity can be accelerated by analyzing historical experiences over the past few decades (Tao et al., 2012a,b; Palosuo et al., 2015). Along this line, recently, an increasing number of