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Historical data provide new insights into response and adaptation of maize production systems to climate change/variability in China

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ABSTRACT

Extensive studies had been conducted to investigate the impacts of climate change on maize growth and yield in recent decades; however, the dynamics of crop husbandry in response and adaptation to climate change were not taken into account. Based on field observations spanning from 1981 to 2009 at 167 agricultural meteorological stations across China, we found that solar radiation and temperature over the observed maize growth period had decreasing trends during 1981–2009, and maize yields were positively correlated with these climate variables in major production regions. The decreasing trends in solar radiation and temperature during maize growth period were mainly ascribed to the adoption of late maturity cultivars with longer reproductive growth period (RGP). The adoption of late maturing cultivars with longer RGP contributed substantially to grain yield increase during the last three decades. The climate trends during maize growth period varied among different production areas. During 1981–2009, decreases in mean temperature, precipitation and solar radiation over maize growth period jointly reduced yield most by 13.2–17.3% in southwestern China, by contrast in northwestern China increases in mean temperature, precipitation and solar radiation jointly increased yield most by 12.9–14.4%. Our findings highlight that the adaptations of maize production system to climate change through shifts of sowing date and genotypes are underway and should be taken into accounted when evaluating climate change impacts.

1. Introduction

Global maize production and consumption have shown constant increases in the past few decades (FAO, 2012). However, maize yield has been documented to be quite vulnerable to climate change/variability in global major maize production regions, using both crop models (Challinor et al., 2007; Tao et al., 2009; Tao and Zhang, 2011) and statistical approaches (Tao et al., 2004, 2012; Schlenker and Roberts, 2009; Cairns et al., 2012; Lobell et al., 2011a,b, 2013; Wang et al., 2014). Therefore, the ability to maintain rates of yield increase in the face of climate change has increasingly been of concern (Cassman, 2007; IPCC 2014; Schlenker and Roberts, 2009; Battisti and Naylor, 2009; de Lattre-Gasquet et al., 2009; Godfray et al., 2010; Olesen et al., 2011; Elsgaard et al., 2012; Lobell et al., 2013). China produces more than 20% of global annual maize and is the second consumer of maize in the world. Hence, the impacts of climate change on maize production in this country have global effects.

Extensive studies document that temperature has increased significantly whereas precipitation trends have been smaller during crop growing season since 1980 at broad regions of the world (Lobell et al., 2011), including China (Tao et al., 2012; Zhang et al., 2015). Increases in mean temperature, extreme high temperature (above 30 °C) stress and drought stress have been indicated to be the major challenges for maize productivity in the face of climate change (Bolanos and Edmeades, 1996; Crafts-Brandner and Salvucci, 2002; IPCC, 2014; Battisti and Naylor, 2009; Lobell et al., 2011b, 2013; Olesen et al., 2011; Tao et al., 2012). Increase in mean temperature can reduce crop growth period and subsequently reduce grain yield (IPCC, 2014). Extreme high temperature stress can desiccate pollen and increase kernel abortion during flowering (Bolanos and Edmeades, 1996; Rattalino Edreira et al., 2011), reduce net photosynthesis rates (Crafts-Brandner and Salvucci, 2002), increase vapor pressure deficit and aggravate drought stress

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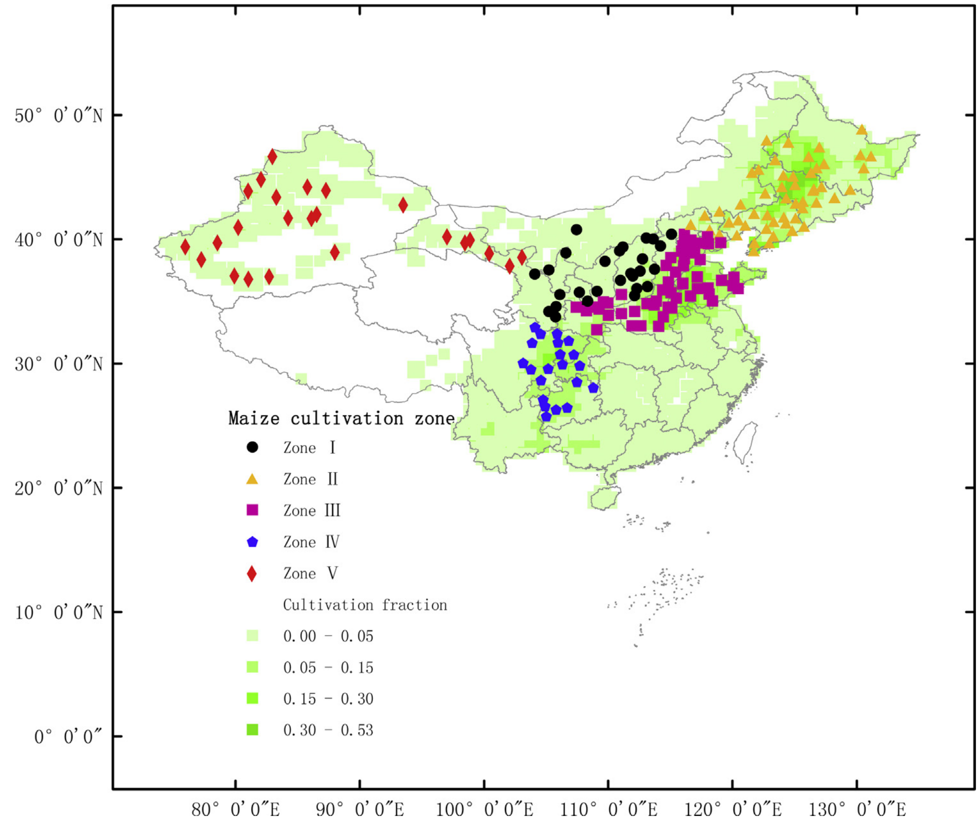

Fig. 1. Maize production zones of China. Each symbol represents the agricultural metrological stations used in the study. The different intensity of green color indicates the contribution of each zone (in cultivation fraction) to maize production in China. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Lobell et al., 2013). The latter mechanism has been indicated to play an important role in affecting maize productivity in some regions of U.S. (Lobell et al., 2013), Africa (Lobell et al., 2011b) and China (Tao et al., 2012) in the past decades.

Nevertheless, the mechanisms, extent and degree of climate impacts on crop growth and productivity under contrasting environments and climate conditions are still imperfectly understood (Lobell et al., 2011b, 2013; Butler and Huybers, 2013; Licker et al., 2013). This particularly applies to the continuous adjustments and adaptations of farmers to climate change such as shifts of sowing dates and cultivars (Welch et al., 2010; Siebert and Ewert, 2012, 2014; Tao et al., 2014a). Crop models and statistical approaches are commonly used to address climate impacts on crop growth and grain yield, both of which, however, have some shortcomings. Crop models do not include potentially relevant processes such as impacts of extremely high temperatures (Lobell and Burke, 2009; Tao et al., 2009; Rötter et al., 2011; Asseng et al., 2013; Ruane et al., 2013; Bassu et al., 2014). Statistical approaches are frequently limited by the quantity and quality of data (Lobell and Burke, 2009). Furthermore, most statistical studies assess climate change and its potential impacts by correlating crop yields at a state or nation from census data with seasonal climate for the same calendar period throughout the whole time series without accounting for the dynamics of cropping systems (i.e., changes of agronomic management practices) (Reidsma et al., 2010; Welch et al., 2010; Tao et al., 2014a). In fact, many farmers select crop cultivars, shift sowing dates and agronomic practices based on the expected meteorological conditions (Tao et al., 2014b). The actual impacts of climate change and variability are largely dependent on farm level response, to accurately understand impacts and adaptation, assessments should consider responses at different levels of organization (Reidsma et al., 2010; Welch et al., 2010).

Historical data from farmer-managed fields would allow us to establish how farmers made changes of agricultural practices based on the weather they observed (Welch et al., 2010; Tao et al., 2014a). In the present study, field observations at 167 agricultural meteorological stations across China (Fig. 1, Table 1) spanning from 1981 to 2009 were used to quantify maize grain yield response considering changes of maize husbandry at different regions of China in the past three decades. We aim to quantify (1) changes of maize phenology and growth durations under the combined effects of climate change, cultivar shifts and sowing dates; (2) climate change during the observed maize growth period; (3) the impacts of climate change on maize yield at different production zones of China accounting for the adaptations (Fig. 1). We try to quantify climate impacts on crop growth and yield under the interactions between climate warming and crop system dynamics, instead of climate warming per se or climate warming impacts without adaptations.

2. Materials and methods

2.1. Experimental stations and data

Experimental observations data on maize cultivars, phenology, yields and management practices during 1981–2009 were from China agricultural meteorological experiment stations, which were maintained by China Meteorological Administration (CMA). There were total 167 geographically and climatologically different agricultural meteorological experiment stations across the major maize production regions (Fig. 1). Based on the maize cultivation zones in China (Tong, 1992), the agricultural meteorological stations were grouped into five zones, i.e., Zone I, Zone II, Zone III, Zone IV, and Zone V (Fig. 1). The information of the dominant cropping system, typical sowing date and maturity date at each zone was presented