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Modelling the impacts of climate change and crop management on phenological trends of spring and winter wheat in China

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A R T I C L E I N F O

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A B S T R A C T

Crop phenology is co-determined by climate change and crop management. Over recent decades, climate change-related alterations in crop phenology have been observed and reported for various global crops. However, attributing changes in crop phenology to climate change is difficult, because there have been concurrent changes in crop management. In this paper, we isolated and quantified the impacts of climate change and crop management on the changes of wheat phenology in China, during the period 1981–2010, using a first-difference multiple regression model. Our results shows: (1) based on observed phenological data, in spring/winter wheat, the mean sowing and emergence date were delayed by 0.91/2.29 and 0.39/0.73 days decade^{-1}; mean anthesis and maturity date advanced by 1.05/2.28 and 0.01/1.42 days decade^{-1}; mean length of vegetative growth period (VGP) and whole growth period (WGP) were shortened by 1.09/2.86 and 0.89/3.69 days decade^{-1}; mean length of reproductive growth period (RGP) was prolonged by 0.55/0.61 days decade^{-1}. (2) At most stations, changing direction of wheat phenology affected by isolated impacts of climate change or crop management was consistent with that affected by combined impacts of climate change and crop management. (3) For observed trends of most phenological stages and growth periods, relative contribution from climate change was smaller than from crop management, and average temperature contributed the most among the three contributors (average temperature, cumulative precipitation, and cumulative sunshine hours) to isolated impacts of climate change on wheat phenology. (4) Crop management over the three decades was shown to have helped reduce the lengths of VGP and WGP, but increase the length of RGP for both spring and winter wheat, implying that shorter-duration varieties with a higher yield or better yield stability in changing climate might have been introduced by farmers.

1. Introduction

The International Panel on Climate Change recently reported that many of the observed changes since the industrial revolution are unprecedented and in the Northern Hemisphere, 1983–2012 was the warmest 30-year period of the last 1400 years (IPCC, 2013). A number of studies have shown that the phenology of wild (Clark et al., 2014; Dai et al., 2014; Gordo and Sanz, 2010) and crop (Anwar et al., 2015; Li et al., 2014) plants has changed in tandem with climate change. Most studies on plants report that as temperature has increased, spring phenology has advanced and autumn phenology has become delayed (Ge et al., 2016; Liu et al., 2016). In recent decades, the earlier flowering and maturity observed in crop plants have been considered to be associated with increasing temperatures (Fujisawa and Kobayashi, 2010; Hu et al., 2005). However, crop phenology is simultaneously affected by crop management (like cultivar shift and sowing date adjustment) and simply attributing crop phenology changes to climate change or even climate warming, is difficult and possibly unjustified (Craufurd and Wheeler, 2009). Various approaches have been used to isolate impacts of climate change from crop management in recent years. One of the most commonly used approaches is crop modelling and has been used for wheat in China (He et al., 2015; Wang et al., 2013; Xiao et al., 2016) and cotton in Pakistan (Ahmad et al., 2017). Another commonly used approach is statistical method, and the key point of this method is to determine the detrended method such as smoothing splines method (Zhang et al., 2013) or moving averages

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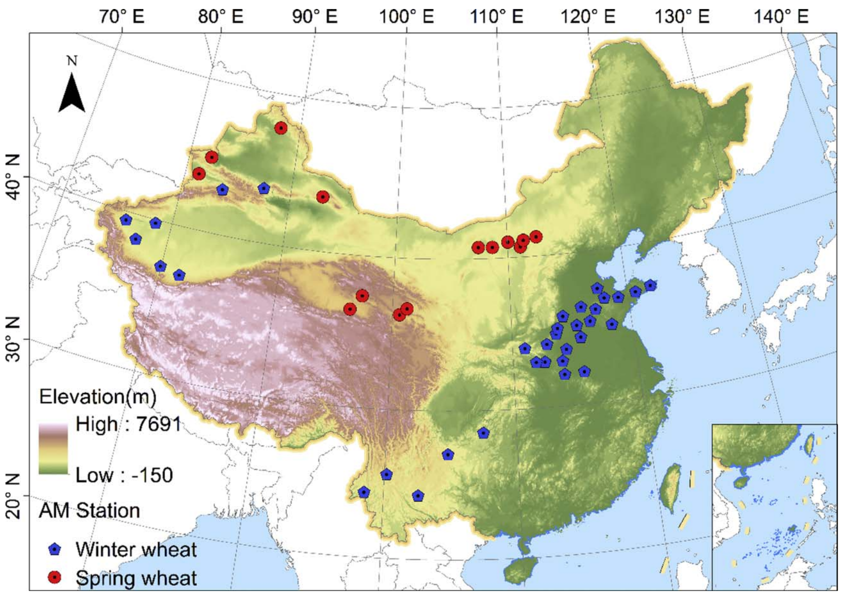

Fig. 1. Spatial distribution of agro-meteorological stations (AM Station).

method (Tao et al., 2013). In addition to these in-silico methods, a field warming experiment was conducted to investigate the responses of soybean phenology to climate warming, using infrared heaters (Zhang et al., 2016).

At the same time, some effective adaptation strategies in response to changing climate have been found and verified during this process. Climate warming accelerated crop growth and shortened the growing periods whereas cultivars shift might prolong the crop growing season, thus adopting cultivars with longer-duration might be an adaptive strategy in responses to warming climate for winter wheat in the North China Plain (Xiao et al., 2013), single rice and early rice in China (Zhang et al., 2013), maize in the U.S. corn belt (Sacks and Kucharik, 2011) and in the North China Plain (Li et al., 2014). Introduction of later-maturing cultivars compensated for the increased temperature effects on wheat phenology, effectively counteracted and even reversed reduction of wheat growth duration due to climate warming (He et al., 2015). Besides, the later-maturity cultivars significantly improved wheat yield and water use efficiency and increasing precipitation during the longer duration of later-maturity cultivars partially compensated for wheat evapotranspiration (Ding et al., 2016). Particularly, for other crops, a shorter-duration cultivars could be an effective choice for adapting climate change as it was reported that earlier anthesis or heading date could avoid extreme heat stress (Nagarajan et al., 2010) and reduce the exposure to drought (Jagadish et al., 2012) during grain-filling period, which would consequently benefit yield. In China, a shorter-duration cultivars for late rice have been introduced by farmers (Tao et al., 2013) and in German, oat with shorter-duration cultivars were advocated in response to climate warming (Siebert and Ewert, 2012). In addition to selecting varieties with appropriate maturation times to mitigate against effects of climate warming on crop yield, adjusting the sowing date may provide an additional option as earlier sowing dates were able to lower the increased trend in average temperature during growing period of spring wheat and then prolonged growing season length as well as potentially benefited productivity (Xiao et al., 2016). In Northeast China, Zhao et al. (2015) found that farmers have taken advantage of the increasing temperatures by adjusting maize sowing dates and alternating cultivars, which prolonged growing season and increased grain yield for spring maize during 1981–2007. Particularly, increasing grain yield from advancing sowing date (1.1–7.3%) was far less than that from introducing later-maturity cultivars (6.5–43.7%) (Zhao et al., 2015).

While a majority of research has reported that increases in temperature have resulted in accelerated crop growth and shortened growing seasons (Wang et al., 2013; Zhang et al., 2013), responses of crop phenology and yield to other functions of climate change, such as precipitation and sunshine hours, and options for crop management and crop breeding have rarely been reported. Quantifying the contribution of these factors to crop phenology and yield would benefit farmers' decision-making on appropriate climate change mitigation strategies to facilitate sustainable agriculture (Anwar et al., 2015; Sacks and Kucharik, 2011).

In this study, we compiled a wheat phenological dataset from 48 agro-meteorology stations in China, covering the period 1981–2010, in order to (1) isolate and quantify impacts of climate change and crop management on changes of wheat phenology; (2) compare relative contribution of climate change and crop management on observed changes of wheat phenology; (3) and further discuss relative contribution of average temperature, cumulative precipitation and cumulative sunshine hours on changes of wheat phenology only affected by climate change.

2. Material and methods

2.1. Agro-meteorological stations and data

The data for wheat phenology in China covering the period of 1981–2010 were collected at 48 agro-meteorological stations operated by the China Meteorological Administration and provincial meteorological administration (Fig. 1). Phenological data include dates of four key phenological stages which are sowing, emergence, anthesis and maturity; phenological data also contain other crop management records, such as cultivars, irrigation and fertilization practices. With these data, lengths during vegetative growth period (VGP, from emergence to anthesis), reproductive growth period (RGP, from anthesis to maturity) and whole growth period (WGP, from sowing to maturity) for every year at each station were calculated. In the study period, the average level of growth situation, climate condition and crop management for spring and winter wheat cropping system was presented in Tables 1 and 2. According to cultivar records, we found that wheat cultivar was shifted approximately every 2–3 years. Therefore, the observations of wheat phenology can be treated as a result of combined impacts of historical climate change and crop management adjustments (especially cultivar shifts). The matched daily weather data, including mean temperature, precipitation and sunshine hours from 1981 to 2011, were downloaded from the China Meteorological Data Website (http://data.cma.cn/site/index.html) operated by the China Meteorological Administration.