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Increased utilization of lengthening growing season and warming temperatures by adjusting sowing dates and cultivar selection for spring maize in Northeast China

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ABSTRACT

Global warming has lengthened the theoretical growing season of spring maize in Northeast China (NEC), and the temperatures during the growing season have increased. In practise, crop producers adjust sowing dates and alternate crop cultivars to take advantage of the lengthening growing season and increasing temperatures. In this study, we used crop data and daily weather data for 1981–2007 at five locations in NEC to quantify the utilization of the lengthening growing season and increasing temperatures by adjusting sowing dates and cultivar selection for spring maize production. If these two positive factors are not fully utilized, then it is important to know the potential impacts of these climatic trends on spring maize grain yields. The results show that in NEC, both the actual and theoretical growing seasons are lengthening, i.e., the sowing dates have been advanced and the maturity dates have been delayed. The actual sowing dates are 1–8 days later and the actual maturity dates are 6–22 days earlier than the theoretical perspective. Advancing sowing dates and changing cultivars led to 0–5 days and 6–26 days extension of the growing season. For the potential thermal time (TT), adjusting the sowing dates decreased the unutilized TT before sowing, while the cultivar selection increased the utilized TT and decreased the unutilized TT after maturity. On average, the unutilized heating resource before sowing is less than that after the maturity date (0.3–1.9% vs. 2.1–7.8%). During 1981–2007, for per day extension of the growing season, the spring maize grain yield increased by 75.2 kg ha^{-1}. The spring maize grain yields have increased by 7.1–57.2% when both early sowing and changing cultivars during 1981–2007. In particular, adjusting the sowing dates increased the grain yield by 1.1–7.3%, which was far less than the increase effect (6.5–43.7%) from switching to late maturing cultivars. Therefore, selecting late maturing cultivars is an important technique to improve maize grain yields in NEC under the global warming context. Nevertheless, if the currently unutilized TT were fully explored, the local spring maize grain yield would have increased by 12.0–38.4%.

1. Introduction

Climate change is considered as a primary environmental problem of the 21st century, and research has increasingly focused on estimating the impacts that may occur under climate change. Agriculture is a key focus because of its direct connection to the climate (Schlenker and Roberts, 2009). The temperature increase may benefit crop production when considering the potential of agronomic adaptations to climate change (Lobell et al., 2008). Temperature are increasing faster in high-latitude areas (IPCC, 2014), and the impact of climate change on agriculture in high-latitude areas has been globally discussed.

Northeast China (NEC), one of three global ‘Golden Maize Belts’, is located in high-latitude area and is significantly affected by climate change. In 2012, the total maize planted area in NEC was 10,680,000 ha, and the regional maize production accounted for 33.8% of the national level. NEC is abundant in natural resources, with ample solar radiation and fertile soil, yet temperature is the main limitation for crop growth and production (Fang et al., 2011; Liu and Lin, 2007; Zhao and Qian, 2004). Under the background of climate warming, the temperature has increased in NEC. From 1961 to 2006, the effective accumulated temperature ≥10 °C

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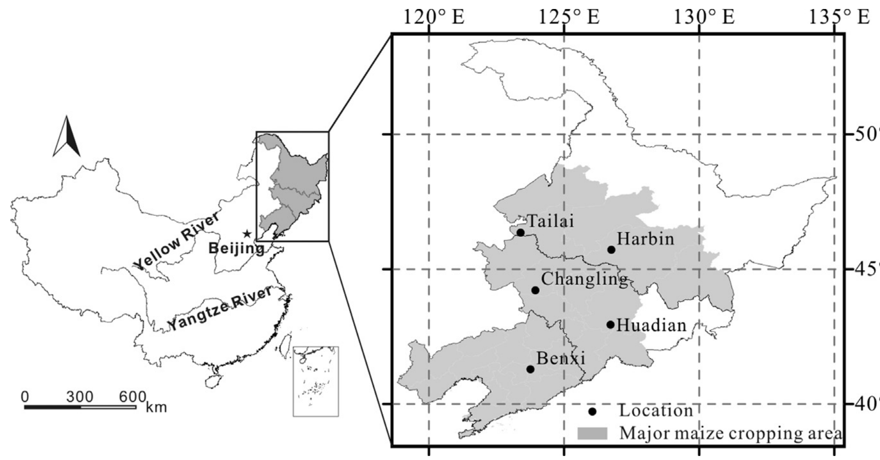

Fig. 1. The location of the three provinces in Northeast China (NEC) in the country (left) and the distribution of the five locations in NEC (right). In the right figure, the solid circles indicate the locations of the study locations in NEC. The gray shade indicates the major maize cropping area in NEC.

during the spring maize growing season generally increased by 200–400 °C days, and the suitable sowing dates were 2–10 days earlier than those in the 1960s (Jia and Guo, 2009). In addition, the potential growing season has lengthened (Zhao et al., 2009), and the risk of low-temperature freezes and frost injury has decreased (Chen et al., 2011; Ma et al., 2008). Without considering the limitation of water, climate warming has benefited the local grain crop production in NEC (Chen et al., 2012; Ma et al., 2008; Zhao and Qian, 2004). The increase in the daily minimum temperature during the maize growing season favors grain yield increases (Chen et al., 2011, 2012; Wang et al., 2014). In particular, every 1 °C increase in the minimum temperatures in May and September increase the maize grain yield by 303 kg ha^{-1} and 284 kg ha^{-1}, respectively (Chen et al., 2011).

Local crop producers have chosen longer growing season crop cultivars to take advantage of the increasing temperatures. The northern planting boundaries have shifted northward by 2° for early maturing cultivars and by 1° for medium and late maturing cultivars, and the suitable planting areas for medium and late maturing cultivars have expanded (Liu et al., 2013b; Zhao et al., 2009, 2014). The grain yields would increase by 9.8% if the early maturing cultivars were replaced by medium maturing cultivars and would increase by 7.1% if the medium maturing cultivars were replaced by late maturing cultivars (Liu et al., 2013b). Li et al. (2011) observed that the emergence dates for maize were advanced by 0.04–0.35 days $year^{-1}$, the maturity dates were delayed by 0.23–0.38 days $year^{-1}$, and the growing season was lengthened by 0.11–0.57 days $year^{-1}$. These changes are consistent with the agro-climatological theory. The actual growing period length was positively correlated with the mean temperature during the growing period at the majority of locations in NEC (Li et al., 2014). In the past 27 years, earlier planting dates caused an increase of up to 4% in the regional spring maize grain yield, whereas long-season cultivars caused a 13–38% increase in the regional spring maize grain yield (Liu et al., 2013a). Therefore, the cropping system has the potential to progressively and actively adapt to global warming for high yield production using comprehensive strategies (Chen et al., 2012).

Although crop producers in NEC have already adjusted the sowing dates and alternated the maize cultivars in order to adapt to the climate warming, the respective and combined contributions of these two measures to the increased utilization of the lengthening growing season and warming temperatures for spring maize and the unutilized growing season and warming temperatures have not been reported yet. Besides, it is important to identify the effects of increased utilization of the lengthening growing season and warming temperatures on maize grain yield and the potential improvement for yield if the unutilized growing season were fully used. The goal of this study is to answer the following questions: (1) How have the theoretical growing season and actual growing season for spring maize changed in NEC? (2) How much of the increased heating resources have been utilized/unutilized by adjusting the sowing date and cultivar selection? (3) What are the quantified effects of increased utilization of the lengthening growing season and warming temperatures on maize grain yield and the potential effect of fully utilizing the lengthening growing season and warming temperatures on maize grain yields?

2. Materials and methods

2.1. Study locations, climate and crop data

Northeast China (115°30′–135°10′E, 38°43′–53°35′N) constitutes of Heilongjiang, Jilin and Liaoning Provinces. According to the statistics almanac of maize and grain crops that are currently planted in the three provinces, the areas where the ratio of the maize area to the grain crop area was equal to or greater than 30% over 2006–2010 were defined as the major maize cropping area. In the major maize cropping area, five locations (two locations in Heilongjiang, two locations in Jilin and one location in Liaoning) were selected for this study. The locations were chosen based on the temperature, water resources, and data completeness from local meteorological and agro-meteorological stations. Daily weather data (including the mean, maximum and minimum temperatures) and crop data (including the sowing date, maturity date, and grain yields) during 1981–2007 were obtained through the China Meteorological Data-Sharing Service System (http://cdc.cma.gov.cn/). Fig. 1 shows the geographical location of the research area and five research locations in the country.

2.2. Calculation of the theoretical growing season and heating resource

As a thermophilic crop, the theoretically safe sowing date and harvest date of maize were determined by the beginning and end of the period that is consistently above 10 °C, respectively (Chen et al., 2012), and the theoretical growing season of maize was determined as the period between the theoretically safe sowing and harvest dates (Chen et al., 2012; Ma et al., 2008). We used the five-day moving-averages method to calculate the period that is consistantly above 10 °C (Qu, 1990).