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Phenological responses of maize to changes in environment when grown at different latitudes in China

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ABSTRACT

Environmental conditions greatly affect the growth of maize. To examine differences in phenological responses of maize (*Zea mays* L.) to climatic factors under different environmental conditions as induced by latitude, experiments were conducted from 2007 to 2010 at 34 sites in seven Chinese provinces located in the north spring maize region of China between latitudes 35°11′ and 48°08′N in the cultivation of hybrid zhengdan958 (ZD958). Latitude is an important geographical factor which significantly affects temperature, sunshine hours, and the duration of crop growth. The findings of this study indicate that for every 1° increase in the latitude, northward, the growth durations of sowing to emergence and emergence to silking were significantly increased by 0.7 d and 1.25 d, respectively as a consequence of lowering temperatures (mean, maximum, and minimum temperatures). Reproductive growth duration (silking to maturity), which was significantly correlated with the precipitation, decreased by 0.8 d with each 1° increase in latitude northward. At higher latitudes, the number of growing degree days (GDD) of maize vegetative growth duration (emergence to silking) was significantly higher, and the GDD of the reproductive growth duration were significantly lower. The average photoperiod during the photoperiod-sensitive phase of maize development across all the experimental sites was 14.9 h with a range of 13.7–15.6 h. Total leaf numbers increased from 18.7 to 23.7 with an average of 21.0 across all experimental sites. Significant and positive linear relationships were found to occur between both latitude and photoperiods and latitude and total leaf number. In the north China spring maize region, the mean growth duration of ZD958 was 143.73 d, which constituted 82.8% of the frost free period, the percentage increasing with higher latitude. These findings strongly indicate that in order to ensure high and stable production of maize in the north spring maize region of China, with its limited heat resources, especially in the high-latitude regions, there is a need to cultivate short-growth-duration cultivars.

1. Introduction

The north spring maize region of China forms the largest maize producing area of the country and includes the provinces of Heilongjiang, Jilin, Liaoning, inner Mongolia, and portions of Shanxi, Hebei, Shaanxi, and Gansu, all of which are mainly located between latitudes 33°24′N (Wudu, Gansu province) and 50°50′N (Heihe, Heilongjiang province). The maize acreage of this region accounts for 42.4% of that of China and 8.8% of that of the world which represents about 46.4% and 8.6% of the total Chinese and global maize grain production, respectively (Li and Wang, 2010; FAO, 2011). The region thus plays a significant role in ensuring food security.

Because of the large latitudinal span of the north spring maize region, the climatic factors within this area vary significantly (Li and Wang, 2010). In this region, the annual accumulated temperature above 10°C, the sunshine hours, and precipitation range from 2000 °C to 3600 °C, 2600 h to 2900 h, and 400–800 mm, respectively, These environmental ranges greatly influence maize development (Warrington and Kanemasu, 1983a). Because of this, the maize cultivars that are widely planted in the north spring maize region are diverse, and the phenomenon of "across-region planting" (planting cultivars in regions in which they can not grow successfully) is a serious issue, especially in the high-latitude region. The need to study phenological responses of maize to changes in environment is therefore important.

Environmental conditions, especially climatic factors, such as temperature, photoperiod, sunshine hours, solar radiation and precipitation, markedly influence maize growth and phenological response (Andrade et al., 1993; Andrade and Ferreiro, 1996; Otegui et al., 1996; Birch et al., 1998; Tollenaar, 1999; Stone et al., 1999; Yang et al., 2004). Among these factors, temperature and photoperiod are the two most important environmental variables influencing the rate of maize development (Duncan, 1975; Hodges, 1991; Birch et al., 1998; Tollenaar, 1999). There is evidence that

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increasing temperature during the vegetative stage of maize leads to a decrease in length of this stage in growth (Cooper and Law, 1978; Liu et al., 2010). Some studies from different agricultural regions have also indicated that, as the temperature is increased, so too is length of the growing season (Chen et al., 2011; De Jong et al., 2001; Bootsma et al., 2004). On the other hand, maize is a short-day plant and photoperiod significantly affects maize growth by influencing growth duration and leaf number. For example, Birch et al. (1998) reported that a photoperiod extension (16.5 h) increased the time from emergence to tassel initiation and increased the number of leaves on five different cultivars differing in maturity and adaptation. Tollenaar (1999) also indicated that the time from sowing to silking increased when the photoperiod was increased from 10 h–20 h during the photoperiod-sensitive phase in maize, but no differences were found in the duration of the grain-filling period. Other workers, however, have reported that the grain-filling period is reduced by an increase in photoperiod (Breuer et al., 1976; Allison and Daynard, 1979).

As important factors relating to crop phenology, heat unit requirements, such as growing degree days (GDD) and accumulated temperature, influence crop growth and development (Stewart et al., 1998; Craufurd et al., 1998; Bartholomew and Williams, 2005). The heat unit required to complete a given growth phase of maize is usually thought to be constant and dependent only upon the cultivars (Wang, 1960; Sacks and Kucharik, 2011). However, several studies have indicated that the heat units required for the completion of a given growth phase of maize are not constant but may vary depending on other environmental conditions. For example, Tataryn (1974) found significant differences between locations and years in the accumulated temperature from emergence to the tasseling and silking stages. In Manitoba, Canada, Major et al. (1983) found that the maize heat unit requirements were dependent upon location.

ZD958, which exhibits high yield, high quality, multi-resistance, and extensive adaptability, has recently been one of the most commonly used maize (Zea mays L.) hybrids in China. It is the most widely distributed cultivar across the north spring maize region and the Huanghuaihai summer maize region of China. In 2009, the planting area of ZD958 increased to 4,540,000 ha, according to the Chinese Agriculture Technology and Popularization Center. Because of global warming (IPCC, 2007), the planting area of ZD958 has been enlarged and the planting region has been extended northward; the north line for safe planting of ZD958 in the Northeast has extended to 47°N (You et al., 2008; Bai et al., 2010). Previous studies on phenological responses of maize have focused mainly on different cultivars on a small scale (e.g. Birch et al., 1998; Tollenaar, 1999). On the other hand this most widely distributed cultivar in China provided an opportunity to study phenological responses of maize to environmental change and the influencing factors on a large on-farm scale. Understanding the effects of changing climatic resources of different latitudes on maize phenological responses is also of importance in establishing safe planting regions whereby the risk of across-region planting of maize using unsuitable cultivars is reduced. The objectives of this study were thus to investigate (1) phenological changes of ZD958 in relation to increasing latitude, and (2) the factors responsible for influencing growth duration with increasing latitude in the north China spring maize region.

2. Materials and methods

2.1. Site description and experimental design

Experiments were conducted in 2007–2010 at 34 locations in seven provinces (Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hebei, Shanxi, Shaanxi) between 35°11′N and 48°08′N in the north spring maize region of China (Fig. 1 and Table 1). Details of the geographical positions and environmental conditions are given in Table 1. This region is in temperate and cold temperate zones with humid and semi-humid climates. The seasons are cold and dry in winter, and warm and short in summer. The annual accumulated temperature above 10 °C, sunshine hours, and precipitation are 2000–3600 °C, 2600–2900 h, and 400–800 mm, respectively. This climate together with good soil quality accounts for the north spring maize region as the main maize producing area in China.

The maize hybrid ZD958, is widely grown in the north spring maize region and the Huanghuaihai summer maize region, which was the reason for its choice in this study. At every experimental site, each plot was 15 m long and 6.5 m wide, consisted of 10 rows

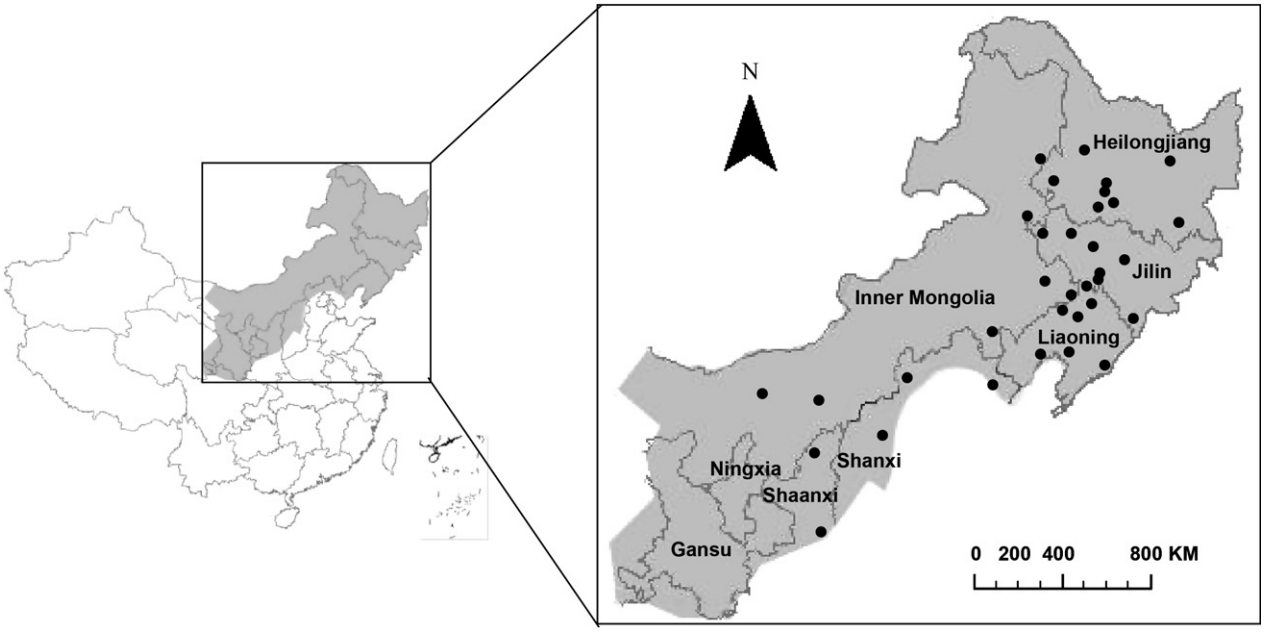

Fig. 1. The north spring maize region of China and the experimental sites distribution. The dots are the 34 experimental stations in this region.