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Late harvest and foliar fungicide acted together to minimize climate change effects on summer maize yield in the North China Plain during 1954–2015

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ABSTRACT

Global climate change has raised many concerns especially on the food security. It becomes increasingly important to understand the underlying mechanisms and to find out strategies to adapt climate change. Climate data from 1954 to 2015 at one representative experimental station in the North China Plain, model simulation, and a 5-year field experiment from 2011 to 2015 worked together to detect effects of climate change on maize yield and adaption methods. In the field experiment, two foliar fungicides “Cabrio” and “Opera” were sprayed at 9-leaf stage of maize to delay leaf senescence under four different plant densities (67,500, 75,000, 82,500, and 90,000 plant ha^{-1}) and two nitrogen levels (120 and 180 N kg ha^{-1}). In the past six decades, growing degree days (GDD) significantly increased at a rate of 4.4 °C yr^{-1}, solar radiation significantly decreased at a rate of 12.93 MJ m^{-2} yr^{-1}, and annual precipitation slightly decreased at the experimental site. The climate change tended to significantly reduce maize yield in the cropping system winter wheat – summer maize in the North China Plain. The reduced growing period (particularly reproductive growing period) by the warming climate could explain the reduced maize yield. Foliar fungicides greatly delayed leaf senescence especially at high plant densities and low nitrogen levels. On average, leaf area index was 2.7 vs. 1.9 between treatments of spraying fungicides and spraying water at harvest. Dry biomass was significantly increased by fungicides especially in the late growing period. Together with increased leaf productivity, 10-day delayed harvest could offset the adverse effects of climate change on maize yield in the past six decades in the North China Plain.

Varieties and crop management that can increase reproductive growing period as well as enhance leaf productivity of maize (particularly in the early grain filling period) are likely to produce more yield and adapt to the progressive climate change.

1. Introduction

An increasing body of evidence indicates that global climate change has adverse effects on crop production (Asseng et al., 2015; Lobell et al., 2011), increasing the challenge in food security with respect to the continuously growing population (Godfray et al., 2010; Foley et al., 2011). The North China Plain is one of the largest agricultural production areas in China, covering a total area of 320,000 km^2, and more than half of which is used for agricultural production. Climate change in this region was estimated to reduce yields of many crops in the past several decades (Chen et al., 2010; Wang et al., 2012; Zhang et al., 2013; Xiao et al., 2016). Warming climate is the most important contributor to the reduced yield by affecting phenological development and crop productivity (Craufurd and Wheeler, 2009; Siebert and Ewert, 2012; Tao et al., 2012). And Warming climate likely reduces yield of summer maize more severely in this region due to the heat stress at the sensitive growth stage such as silking (Edreira et al., 2011; Zhang et al., 2015a, 2015b).

To adapt the warming climate, maize cultivars with a longer growing period are supposed to offset the negative effects of climate change (Sacks and Kucharik, 2011; Liu et al., 2013; Xiao et al., 2016). As well, adjustment of sowing time (i.e. earlier or delayed sowing, depending on the regions) was also estimated to be an effective strategy (Kucharik, 2008; Zhao et al., 2015; Dobor et al., 2016), especially to

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avoid the high temperature coincidence with sensitive stage of reproductive growth (Prasad et al., 2002; Hedhly et al., 2009). However, these adaption strategies would be less effective in the double cropping system winter wheat – summer maize in the North China Plain. First, most of the modern maize cultivars cannot reach physiological maturity at normal harvest due to the short growing season allowed in the double cropping system (more or less 100 days, Sun et al., 2007). On the other hand, it is difficult to greatly advance sowing of maize, which would greatly reduce wheat yield due to the early harvest. Double-delay cropping technology (i.e. delayed harvest in maize and delayed sowing in wheat) could increase yield in both maize and wheat (Sun et al., 2007; Wang et al., 2012). But the delay in the harvest of maize is limited due to the low temperature at late growing period, which can hinder grain filling (Thakur et al., 2010). And, too late sowing would reduce wheat yield in the cropping system of winter wheat – summer maize (Sun et al., 2007).

Besides, solar radiation in the early grain filling period of summer maize is limited due to the cloudy weather in the North China Plain, restricting maize yield increase (Xu et al., 2013). With the climate change and environmental stress in mind, to further increase summer maize yield will become more difficult in this region. Increasing plant density with modern cultivars that are tolerant to high plant population is considered as the most important strategy to increase maize yield (Tokatlidis and Koutroubas, 2004; Hernández et al., 2014). The dense plant population, however, can result in ear rot and mycotoxin contamination in maize kernels (Blandino et al., 2008; Mukanga et al., 2010), and accelerate leaf senescence (Borrás et al., 2003; Antonietta et al., 2014) especially in hot and humid environment. With the fast development in agriculture, agro-ecology and sustainable agriculture raise more concerns (Bellon and Hemptinne, 2012; Velten et al., 2015). Reducing chemical fertilizer input such as nitrogen that can reduce leaf productivity, as well as maintaining high grain yield of maize will become a challenge, particularly in the North China Plain (Chen et al., 2014; Wu and Ma, 2015).

Increasing leaf productivity and delaying leaf senescence have important implications to yield increases of many crops (Greef, 1994; Bertelsen et al., 2001; Valentinuz and Tollenaar, 2004). For this, foliar fungicides have been widely used in the United States (Munkvold et al., 2008; Blandino et al., 2012) and other countries such as Canada (Hooker et al., 2008) and China (Wan et al., 2007) in the past decade. Fungicides such as pyraclostrobin and propiconazole can control foliar diseases and enable many crops to achieve a high physiological benefit especially at late growing period, thus delaying leaf senescence and increasing yield (Blandino et al., 2012; Joshi et al., 2014; Testa et al., 2015). Previous studies showed that foliar fungicides “Cabrio®” (active ingredient: pyraclostrobin) and “Opera®” (active ingredient: pyraclostrobin + epoxiconazole) released by BASF can efficiently delay leaf senescence and increase yield of maize (You et al., 2012; Lazo and Ascencio, 2014; Zhang et al., 2014). The use of these fungicides might be a useful strategy to offset the adverse effects of climate change and environmental stress on the maize yield in the North China Plain.

Hypothetically, the adverse effects of climate change on maize yield can be offset by extending growing period but to only some extent because of the limited growing period of maize in the double cropping system in the North China Plain. Alongside the extended growing period, promoting leaf productivity is speculated to further offset the effects of climate change. The objectives of this study were (i) to detect the adverse effects of climate change on summer maize yield in the North China Plain in the past six decades, (ii) to reduce the adverse effects of climate change and environmental stress, and (iii) to find out possible strategies to further increase maize yield in this region.

2. Materials and methods

2.1. Experimental site and climate database

The field experiment was conducted in 2011–2015 at Wuqiao Experimental Station (37°41′02″N, 116°37′23″E) of China Agricultural University on a loam soil, located in the east of North China Plain. This region is in a warm temperature zone with a cold and dry winter and a hot and short summer. Mean annual temperature is 14.0 °C, mean annual precipitation is 550 mm with a large inter-year variation, and accumulated solar radiation is 4600–5800 MJ m^{-2} in the past six decades. Meteorological data from 1954 to 2015 for Wuqiao were obtained from the China Meteorological Data Sharing Service System (http://www.cdc.nmic.cn; Botou site). The downloaded climate data include daily solar radiation, precipitation, relative humidity of the air, wind speed, and daily mean, maximum and minimum temperature. Annual solar radiation and precipitation were the sum of daily solar radiation and precipitation, respectively. Growing degree days (GDD) per year was the sum of daily GDD. Daily GDD = (maximum temperature + minimum temperature)/2–10 °C, and daily GDD was not summed up when it was less than 0 °C.

The experiment was arranged in different experimental designs in different years, a split plot design with foliar fungicides as main factor and plant density or nitrogen as second factor in 2012–2015 (Table 1). Maize hybrid ZD958 that has been widely adopted in the North China Plain in the past decades was used. Foliar fungicides “Cabrio” in 2011–2014 and “Opera” in 2015 were sprayed at 9-leaf stage, respectively, in a concentration of 1.5 ml L^{-1}, corresponding to 500 ml fungicides ha^{-1}. The control treatment was to spray the same amount of H_2O at 9-leaf stage. Plant densities ranged from 67,500 to 90,000 plants ha^{-1}, differing between years (Table 1). At sowing, 60 kg N ha^{-1} was applied in all the experimental years 2011–2015, and an extra 60 kg N ha^{-1} was added at 6-leaf stage in the nitrogen treatment of 120 N ha^{-1} in 2011; in the treatment of 180 ha^{-1}, an extra 120 kg N ha^{-1} was applied at 6-leaf stage. Other fertilizers such as 105 kg P_2O_5 ha^{-1}, 120 kg K_2O ha^{-1}, and 15.0 kg $ZnSO_4$ ha^{-1} were applied together at sowing. The plot size was 6 × 10 m^2 with a row spacing of 0.6 m. Each treatment had at least three replicates. Irrigation was performed at any growth stage to avoid drought stress.

Maize seeds were sown into the standing wheat stubble immediately after harvest of winter wheat without any tillage, which was performed at the middle or late June. The fields were overplanted and thinned to

Table 1
Field experiment, experimental treatments (i.e. foliar fungicides, plant density, and nitrogen), and sowing and harvest time from 2011 to 2015.

Year	Foliar fungicides	Density[c] plant ha^{-1}	Nitrogen kg ha^{-1}	Sowing	Harvest
2011	Cabiro[a]	75,000 90,000	120; 180	24/06/2011	06/10/2011
2012	Cabiro[a]	67,500 90,000	180	15/06/2012	04/10/2012
2013 - 2014	Cabiro[a]	67,500 82,500[d]	180	15/06/2013 19/06/2014	01/10/2013 02/10/2014
2015	Opera[b]	90,000	180	10/06/2015	05/10/2015

[a] Foliar fungicides “Cabrio” at the level of 500 ml ha^{-1} was sprayed at 9-leaf stage.
[b] Foliar fungicides “Opera” at the level of 500 ml ha^{-1} was sprayed at 9-leaf stage.
[c] Density treatments were classified into two groups, low density treatment including 67,500 and 75,000 plants ha^{-1} and high density treatment including 82,500 and 90,000 plants ha^{-1}.
[d] Two plant densities 67,500 and 82,500 plants ha^{-1} were used in 2013, and only 82,500 plants ha^{-1} in 2014.