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Research paper

Distribution of high-yield and high-yield-stability zones for maize yield potential in the main growing regions in China

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ABSTRACT

Understanding the distribution of zones possessing both high yield and high yield stability (high-stable zones) for maize (*Zea mays* L.) yield potential is essential for optimized distribution and improvement of maize production with limited resources. In this study, the well-calibrated and validated Agricultural Production Systems sIMulator (APSIM-Maize) model with observed phenology and yield of widely planted hybrids, was applied to simulate three levels of yield potentials [radiation-temperature yield potential (Y_p), climatic yield potential (Y_{pw}) and soil-climatic yield potential (Y_{pws})] at 331 meteorology stations in the three main growing regions in China [the North China spring maize region (NCS), the Huanghuaihai summer maize region (HS) and the Southwest China mountain maize region (SCM)] during 1981–2010. According to the comprehensive analysis of both average and CVs for the three levels of yield potential, the high-stable zone for Y_p was located in the southeastern and central portions of NCS, while both high-stable zones for Y_{pw} and Y_{pws} were located in eastern NCS, accounting for 16.4% and 20.0% of the area, respectively. In HS, the high-stable zone for Y_p was located in the northern portions and accounted for 12.8% of the entire area in this region, while the percentages of high-stable zones for Y_{pw} and Y_{pws} increased to 30.4% and 35.0%, respectively, and were mainly located in the southern and eastern portions. In SCM, the high-stable zone for Y_p was located in the southwestern portions and occupied 24.5% of the areas; the high-stable zones for Y_{pw} and Y_{pws} were found in eastern portions and accounted for 17.1% and 20.1% of the land area in this region, respectively. Yield stability was more negatively affected by rain in NCS and HS (38.9% and 34.3%, respectively) than in SCM (8.2%), while yield level was reduced by rain in more areas in SCM (19.1%). Moreover, the effects of soil on yield level and stability were limited in all the three regions.

1. Introduction

Maize (*Zea mays* L.) is an extremely important cereal crop and provides at least 30% of daily caloric intake to more than 4.5 billion people in 94 developing countries (CGIAR, 2016), where the demand for maize is projected to double between now and 2050 (CIMMYT, 2011). Improvement in maize productivity is critical to meet increasing demand with limited crop land (Chen et al., 2017; Licker et al., 2010; Wart et al., 2013). As the second largest producer and consumer of maize, this issue is more serious in China because of its large population and insufficient crop land. In China, maize yields have been affected by increasing temperature and uncertain precipitation (Lv et al., 2015; Tao et al., 2015; Wang et al., 2014) in the last 30 years. The recorded maize grain yield had increased in a nearly linear fashion since 1961, but the increasing trend has stagnated at approximately 5000 kg ha^{-1} since 1995 (FAO, 2014; Meng et al., 2013) and across 52% of the maize-growing areas (Ray et al., 2012). Therefore, it is essential to elucidate the optimized distribution to improve maize production with different limited resources throughout China.

In China, maize is widely cultivated and growing areas are divided into six regions (Li and Wang, 2010). Among the six regions, the North China spring maize (NCS), Huanghuaihai summer maize (HS), and Southwest China mountain maize regions (SCM) accounted for ~90% of the sowing areas and ~96% of the total production in the whole country (Li and Wang, 2010); we selected these leading regions in this research (Fig. 1). Yield potential is the yield of a cultivar when grown in environments to which it is adapted, with nutrients and water (resources) non-limiting and with pests, diseases, and other stresses effectively controlled (Fischer, 2015; Grassini et al., 2011). Because of limiting factors, yield potential varies with location. The radiation-temperature yield potential (Y_p, using the term ‘yield potential’ in a lot of studies directly) is the yield limited only by the solar radiation and temperature, with optimal resources and without stresses. Since it is difficult to control the solar radiation and temperature conditions in the

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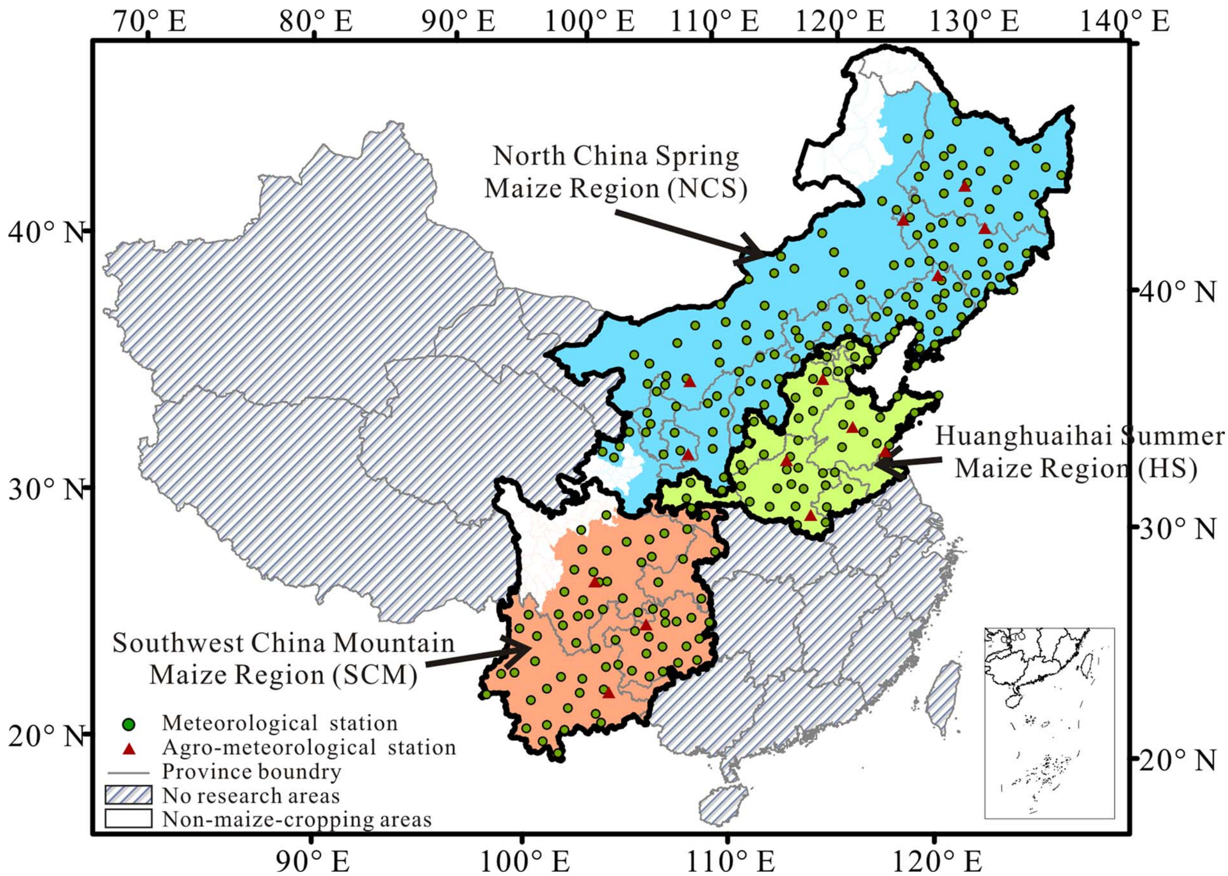

Fig. 1. Locations of the three primary maize growing regions in China and distribution of the meteorological stations in each region.

field, Y_p is considered as the maximum yield that could be reached in any given environment with optimal resources and management (Evans and Ficsher, 1999), and it can be referenced in the areas with irrigation conditions. However, most of the maize fields are rain-fed in the main growing regions in China (Liu et al., 2017). The yield potential under water-limited and optimal soil conditions [climatic yield potential (Y_{pw})] should be the maximum yield in most of the maize fields in the research regions. Additionally, since there are an abundance of soil types (Huang, 2005), yield potential under water-limited and actual soil conditions [soil-climatic yield potential (Y_{pws})] reflect the effects of water and soil on crop growth. Coupled with local agricultural conditions, spatial knowledge on Y_p, Y_{pw} and Y_{pws} is essential to under the best distribution for higher yield (Liu et al., 2016a). While it may be challenging to determine the potential conditions for the optimal management of crop and soil factors (Lobell et al., 2009), it is important to understand the magnitudes of each level of yield potential in the different regions. Additionally, yield stability (consistently producing high yield across environments) influences food security. Disasters arising from increased probability, frequency, and severity of extreme events can cause major damage to crops and infrastructure, potentially threatening local and global food security (Lesk et al., 2016). It is important to know the effects of different factors on yield stability (Guan et al., 2017; Katz and Brown, 1992; Rosenzweig et al., 2001); however, few studies have researched this topic.

By comparing different levels of yield potential, we can determine the main limiting factors in each region. According to the definitions of the three yield potentials, the reduction in yield between Y_p and Y_{pw} was caused by insufficient water supply during the maize growing season (Fischer, 2015). Therefore, more consideration should be placed on the extreme drought events in the areas with a reduction in yield stability. Irrigation is the essential measure to increase Y_{pw} to fully achieve Y_p (Liu et al., 2017). However, because the rain-fed condition in most of the maize fields, the differences between Y_{pw} and Y_{pws} were selected to show the constraint of soil on the yield in the research regions, which could be improved with better agricultural management practices (Liu et al., 2016b).

Yield potential can be estimated in several ways including crop model simulation, field experiments and yield contests, and maximum farmer yields (Lobell et al., 2011). Compared with other methods, crop models reflect the integrated effects of limited factors and offset the space and time limitation. In this study, we used the Agricultural Production Systems sIMulator (APSIM-Maize) to estimate Y_p, Y_{pw}, and Y_{pws} across the three primary maize growing regions in China from 1981 to 2010. The purpose of this study was to: (1) investigate the distribution of zones with high yield and high yield stability (high-stable zones) for maize Y_p, Y_{pw}, and Y_{pws} and (2) find the areas in each region where both yield and stability were reduced by rain and soil. Coupled with different agricultural conditions, the results provide a scientific basis for optimal maize growing distribution, and elucidate ways to improve yield and yield stability with limited resources in the main growing regions in China.

2. Materials and methods

2.1. Study areas and climatic data

Historical climate data from 331 meteorological stations in the three regions during the period of 1981–2010 were obtained from the China Meteorological Administration climate data-sharing service system. The observed daily weather conditions included: maximum temperature, minimum temperature, average relative humidity, minimum relative humidity, wind speed, precipitation, and sunshine duration. The five-day moving averages method was used to define the period consecutively exceeding 10 °C (Qu, 1990) and accumulated temperature

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