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Temporal and spatial changes of maize yield potentials and yield gaps in the past three decades in China

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ABSTRACT

The precise spatially explicit knowledge about crop yield potentials and yield gaps is essential to guide sustainable intensification of agriculture. In this study, the maize yield potentials from 1980 to 2008 across the major maize production regions of China were firstly estimated by county using ensemble simulation of a well-validated large scale crop model, i.e., MCWLA-Maize model. Then, the temporal and spatial patterns of maize yield potentials and yield gaps during 1980–2008 were presented and analyzed. The results showed that maize yields became stagnated at 32.4% of maize-growing areas during the period. In the major maize production regions, i.e., northeastern China, the North China Plain (NCP) and southwestern China, yield gap percentages were generally less than 40% and particularly less than 20% in some areas. By contrast, in northern and southern China, where actual yields were relatively lower, yield gap percentages were generally larger than 40%. The areas with yield gap percentages less than 20% and less than 40% accounted for 8.2% and 27.6% of maize-growing areas, respectively. During the period, yield potentials decreased in the NCP and southwestern China due to increase in temperature and decrease in solar radiation; by contrast, increased in northern, northeastern and southeastern China due to increases in both temperature and solar radiation. Yield gap percentages decreased generally by ∼∼2% per year across the major maize production regions, although increased in some areas in northern and northeastern China. The shrinking of yield gap was due to increases in actual yields and decreases in yield potentials in the NCP and southwestern China; and due to larger increases in actual yields than in yield potentials in northeastern and southeastern China. The results highlight the importance of sustainable intensification of agriculture to close yield gaps, as well as breeding new cultivars to increase yield potentials, to meet the increasing food demand.

1. Introduction

The global demand for food is expected to roughly double by 2050 (Godfray et al., 2010; Tilman et al., 2011), however yields of some important crops are reported to be stagnating in some regions around the world (Cassman et al., 2003; Brisson et al., 2010; Ray et al., 2012). Many irrigated cropping systems have yields at or approaching 80% of yield potential ceiling (Cassman, 1999; Lobell et al., 2009; Ramankutty, 2010; van Wart et al., 2013). This implies that yield gains in these regions will be small in the near future, and yields may even decline if yield potentials are reduced because of climate change. In order to increase crop yields and meet the increasing food demand, it is critical to understand the magnitudes and causes of yield potentials and yield gaps (i.e., differences between yield potential and the actual yield achieved by farmers) (Cassman, 1999; Lobell et al., 2009). The precise spatially explicit knowledge about yield potentials and yield gaps is essential to guide sustainable intensification of agriculture (van Ittersum et al., 2013).

Since China is one of the major crop production and consumption countries, trends in actual yields and yield gaps for major crops in China have been of key concern (Cassman, 1999). Previous studies showed that although aggregate rice yields in China appeared to continue at a linear rate of increase established during the past several decades, yields were approaching the 80% yield potential threshold in several major rice production regions

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(Cassman et al., 2003; Licker et al., 2010; Mueller et al., 2012; Ray et al., 2012; Xiong et al., 2014; Zhang et al., 2014a). As the second largest maize producer and consumer, China accounts for more than 20% of total production annually in the world. Chinese maize harvest area and production amounted to 34.97 M ha and 1.65 M tones, respectively, in 2012 (FAO, 2013). Therefore, the changes in maize yields and yield potential in China have become a major research topic (Licker et al., 2010; Ray et al., 2012; Liang et al., 2011; Liu et al., 2012; Meng et al., 2013; Wang et al., 2014a). For examples, by comparing existing yields to climate-specific attainable yields, Licker et al. (2010) showed that maize in eastern China generally had high yield gaps although this region was heavily irrigated. Ray et al. (2012) showed that maize yields had stagnated across 52% of the maize-growing areas in China. Liang et al. (2011) showed that the aggregate yield for the wheat–maize double crops grown in the 2004–2005 season across the six counties in Hebei province of the North China Plain (NCP) was 72% of the average yield recorded from on-farm trials and 60% of the simulated average yield potential. By applying the APSIM-Maize model to estimate yield potential and yield gaps, Liu et al. (2012) showed that on-farm maize yields were, on average, only 51% of yield potentials in northeastern China. By comparing with the yield potentials simulated by the Hybrid-Maize Model at 50 representative sites, Meng et al. (2013) showed that the average farmer's maize yields attained 48–56% of the yield potentials in China. Wang et al. (2014a), using APSIM model and long-term maize yield records (1981–2009) from 10 sites to investigate the changes in maize yield potentials and yield gaps in the NCP, showed that maize yield potentials had a general declining trend and maize yield gaps continued to shrink; at 2 of the 10 studied sites, the maize yield potentials had already been achieved. The inconsistencies in yield gap analyses in the literatures are mainly due to lack of consistency in yield potential estimations. Yield potentials can be estimated in a variety of ways including crop model simulation, field experiments and yield contests, and maximum farmer yields (Lobell et al., 2009). Model simulations are likely to provide the most accurate estimate of the yield potential ceiling for specific fields and for regions when information on spatial variation of model inputs is available, despite there are some shortcomings and uncertainties (Lobell et al., 2009). However, the uncertainties and variations in different crop models can result in different estimations (Asseng et al., 2013; Bassu et al., 2014). Moreover, site-specific and/or cultivar-specific estimation of yield potential can have poor representativeness at regional and national scales (van Wart et al., 2013). And the previous attempts to estimate yield potentials at a national level and global level have been too coarse and general (van Wart et al., 2013).

In this study, the process-based general Model to capture the Crop-weather relationship over a Large Area (MCWLA) for maize crop (MCWLA-Maize) (Tao et al., 2009a) was applied to estimate

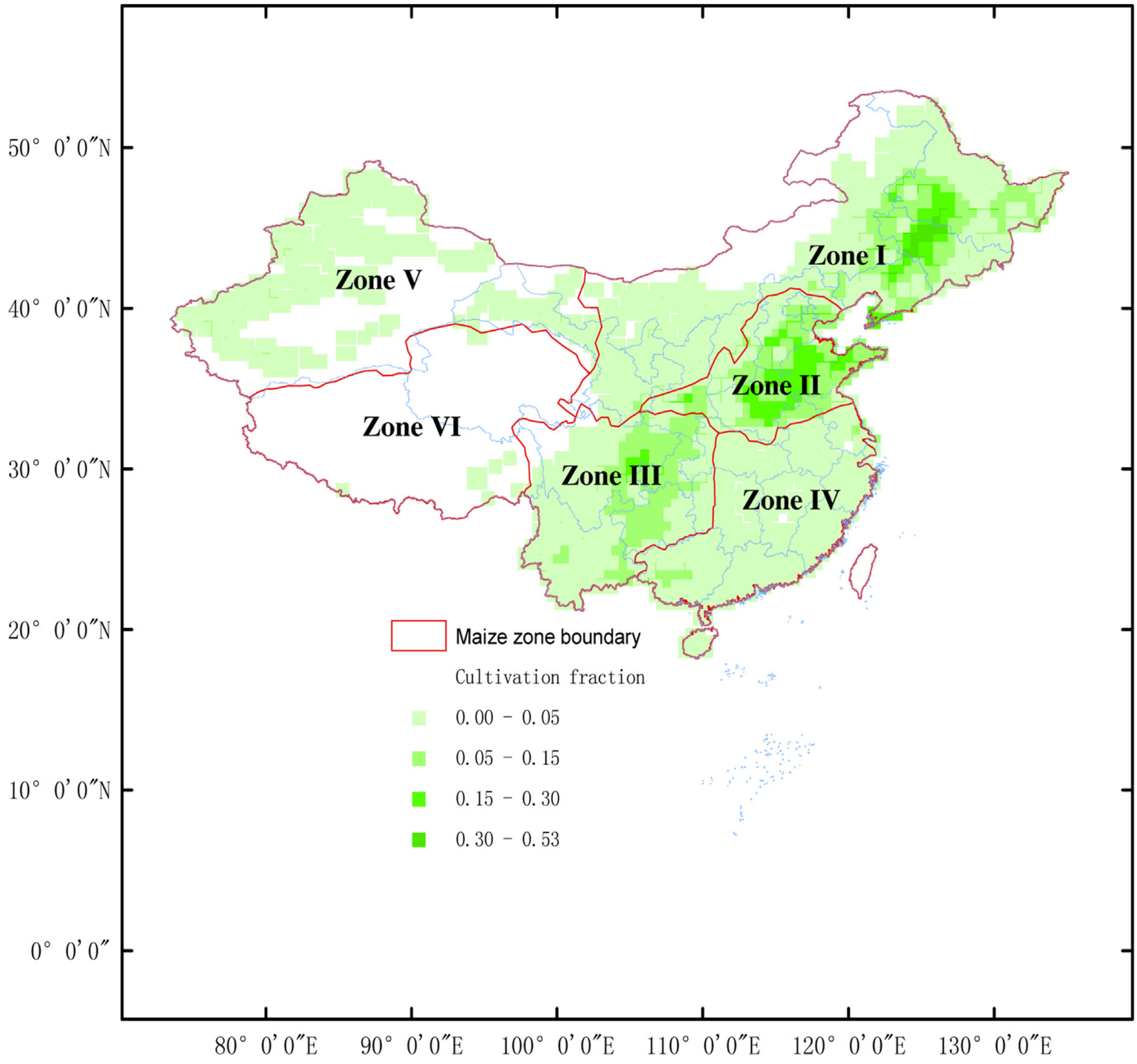

Fig. 1. Maize cultivation fraction and cultivation zones in China.