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Does maize hybrid intercropping increase yield due to border effects?

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ABSTRACT

In China, maize hybrid intercropping has been practiced by farmers for its higher grain yield, but the underlying mechanism remains unclear. Here, we present field experimental data on yield and yield components of maize hybrid cultivars under intercropping system. These cultivars differ in plant heights (i.e. Zhengdan958 with plant height of 270 cm, Xianyu335 of 325 cm, Huayi5 of 330 cm, and Xundan20 of 273 cm) and were planted in 8 different intercropping configurations, along with 6 sole cropping treatments in two years. Yield advantages of 0.15–1.7 t ha^{-1} were detected under maize hybrid intercropping treatments as compared to sole cropping treatments in one year. Seasonal climate variation and hybrid configuration influenced the interspecific interactions between hybrid cultivars, resulting in different increase of grain yield. Cultivar Zhengdan958 had a lower grain yield per plant and thousand kernel weight under intercropping comparing to sole cropping, while cultivars Xianyu335 and Huayi5 under intercropping increased grain yield per plant and thousand kernel weight, resulting in a land equivalent ratio greater than 1. Additionally, the land equivalent ratio was positively and significantly ($P < 0.01$) correlated with border effects. This study indicates that there is potential for yield improvement of maize hybrids through intercropping system in China, and the land equivalent ratio was affected by hybrids used in intercropping and seasonal climate variation.

1. Introduction

Achieving grain supply security with limited arable land is a major challenge in the twenty-first century because of the changing climate and increasing global population (Gong et al., 2015). Thus, further increasing crop yield in the future is needed for food security (Spiertz, 2013). Maize (*Zea mays* L.), as a C4 plant, plays an increasingly vital role in global food security. Breeders have successfully increased maize grain yield in the U.S. corn-belt over the past 80 years, with single-cross hybrids being utilized for the past 50 years (Reyes et al., 2015).

Cultivation methods also play an important role in increasing maize yield. This has been achieved by integrated soil–crop system management (Chen et al., 2014), including the use of maize hybrids and in-season nitrogen management (Yan et al., 2014), different row arrangement (Haegele et al., 2014), and ridge furrows with film mulching in cold, semiarid areas (Eldoma et al., 2016).

An advantage of cultivar mixtures for yield increase has also been demonstrated, not only due to suppression of fungal diseases (Zhu et al., 2000; Huang et al., 2012), but also as a result of improved growth of the cultivar mixtures. Yield increase from cultivar mixtures was observed in winter wheat (Fang et al., 2014; Döring et al., 2015; Wang et al., 2016), winter barley (Newton et al., 2008), and rice (Revilla-Molina et al., 2009).

Intercropping of different cultivars of the same species offers a type of cultivar mixture to take advantage of the border effect for increased crop growth and yield. For rice, previous studies showed that increase in grain yield occurred in the outermost row but not in the second and third outermost rows compared with the centre rows for two hybrid rice varieties (Wang et al., 2013). Gomez and De Datta (1971) analysed eight rice yield trials and found that the increase in grain yield of the border rows over the centre rows ranged from 63% to 159%, with an average of 116%. Border effects usually occur when the unplanted alley is left between plots, and adjacent plots are planted with different varieties or have different fertilizer treatments (Gomez and De Datta, 1971; Gomez, 1972).

In the North China Plain (NCP), summer maize has been generally grown in sole crops in the past. In recent years, maize hybrid intercropping has been experimented due to its potential for greater grain yield over a sole hybrid. However, there is a lack of studies on the underlying mechanism of the yield increase in such intercropping. We

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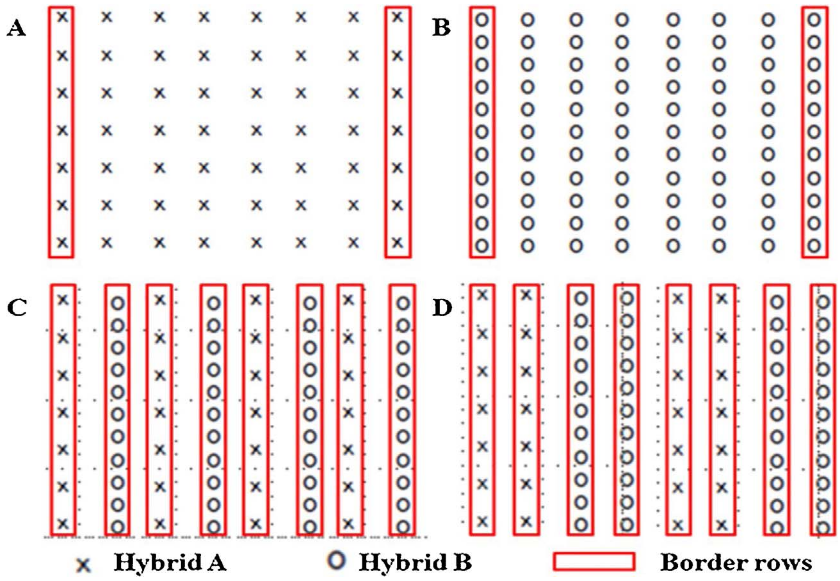

Fig. 1. Schematic illustration of the border rows in sole crop system (panels A–B) and intercropping system (panels C–D), assuming hybrid A and B have different plant heights.

hypothesize that maize hybrids with different plant heights sown in different rows (cultivar intercropping system) could create border rows and result in yield increase compared to sole crops (Fig. 1).

The objectives of this study are: 1) to assess the performance of different maize hybrid cultivars under intercropping as compared to sole cropping, 2) to investigate the yield advantage under the intercropping of two maize hybrids with different or similar plant heights, and (3) to quantify the border effects on maize yield of intercropping.

2. Materials and methods

2.1. Experimental site and climate

Field experiments were conducted in 2014 and 2015 at Wuqiao Experiment Station of China Agricultural University in Hebei province, China (37°41N, 116°37E, and 18 m above sea level). The soil is clay-loam soil with topsoil (0–40 cm) contained approximately 11.8 g kg^{-1} organic matter, 0.8 g kg^{-1} total N, 46.8 mg kg^{-1} available P and 76.8 mg kg^{-1} available K. The 10-day accumulated rainfall and daily average air temperature during the summer maize growing seasons (Jun–Oct) are shown in Fig. 2.

2.2. Experimental design

The experiments were designed to compare intercropping (cultivar mixtures) with sole cropping (one hybrid) and to quantify border effects in both years. Each plot was 300 m^2 in area (10 m × 30 m, 12 rows) with four replicates. Rows were aligned along the west–east direction with a 1 m buffer between plots. The summer maize hybrids ‘Zhengdan958’ (plant height, approximately 270 cm), ‘Xianyu335’ (plant height, approximately 325 cm), ‘Huayi5’ (plant height, approximately 330 cm), and ‘Xundan20’ (plant height, approximately 273 cm) was used because they are widely planted in China.

There are five treatments (3 sole cropping treatments and 2 intercropping treatments) in 2014 and nine treatments in 2015 (3 sole cropping treatments and 6 intercropping treatments) (Table 1 and Fig. 3). The sole cropping and intercropping treatments were sown on June 16, 2014 and June 14, 2015 respectively, both with plant density of 75,000 plant ha^{-1} according to local practice and row space of 60 cm. Each plot received 240 kg ha^{-1} nitrogen in form of urea, 90 kg ha^{-1} P_2O_5 as superphosphate and 130 kg ha^{-1} K_2O as K_2SO_4 before sowing. Each plot was irrigated with 60 mm of water immediately after sowing. No further fertilizer or water was applied during the growing seasons.

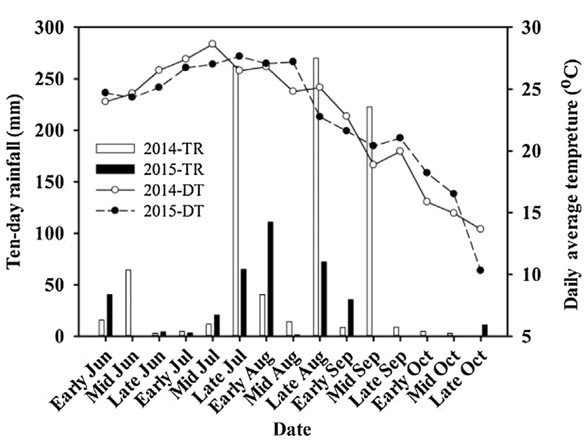

Fig. 2. Ten-day total rainfall (TR) and daily average temperature (DT) in summer maize growing periods in 2014 and 2015.

Table 1
Experimental treatments in this study.

Year	Symbol	Cropping Systems	Remarks
2014	SZ	Sole cropping	Sole cropping with cultivar Zhengdan958
	SX	Sole cropping	Sole cropping with cultivar Xianyu335
	SH	Sole cropping	Sole cropping with cultivar Huayi5
	ZX1:1	Intercropping	Intercropping with 1 row Zhengdan958 and 1 row Xianyu335
	ZH1:1	Intercropping	Intercropping with 1 row Zhengdan958 and 1 row Huayi5
2015	SZ	Sole cropping	Sole cropping with cultivar Zhengdan958
	SX	Sole cropping	Sole cropping with cultivar Xianyu335
	SD	Sole cropping	Sole cropping with cultivar Xundan20
	ZX1:1	Intercropping	Intercropping with 1 row Zhengdan958 and 1 row Xianyu335
	ZX2:2	Intercropping	Intercropping with 2 row Zhengdan958 and 2 row Xianyu335
	ZX3:3	Intercropping	Intercropping with 3 row Zhengdan958 and 3 row Xianyu335
	ZD1:1	Intercropping	Intercropping with 1 row Zhengdan958 and 1 row Xundan20
	ZD2:2	Intercropping	Intercropping with 2 row Zhengdan958 and 2 row Xundan20
	ZD3:3	Intercropping	Intercropping with 3 row Zhengdan958 and 3 row Xundan20