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Optimised sowing date enhances crop resilience towards size-asymmetric competition and reduces the yield difference between intercropped and sole maize

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ABSTRACT

Intercropping is becoming an attractive and profitable agricultural practice, and a growing body of literature investigate on the plant–plant interaction between intercrops. However, little is known on how sowing date alters interspecific interaction causing a yield difference between the intercropped and sole crop. A two-year field experiment was undertaken to investigate the impacts of varying competitive interaction on plant growth and grain yield of a maize/watermelon intercropping system. Both intercropped and sole maize were sown 28 days, 33 days and 38 days after a consistent transplanting date for watermelon to generate varying intensities of asymmetric competition between species in the maize/watermelon intercropping system. Growth patterns were monitored over two years and described with logistic growth curves. Compared with conventional sowing date, changes in maize sowing date significantly enhanced the intercropped maize grain yield by 21%–42%, but barely affected the sole maize yield, consequently reducing the yield difference between intercropped and sole maize. An earlier sowing date empowered the intercropped maize to reach the maximum absolute growth rate 11 days earlier, producing greater aboveground biomass and larger growth rate over its growing period, and thereby enhanced the maize resilience towards size-asymmetric competition derived from the presence of watermelon. Changes in the maize sowing date did not alter the fruit yield of intercropped watermelon in the most cases, but overmuch improvement in the aggressivity and growth rate of the maize sown on 13 June in 2014 caused a 16% reduction in fruit yield. We concluded that the yield difference can be reduced by adjusting the sowing date to manipulate plant–plant interaction between intercrops, and an optimal sowing date not only enhances crop growth but also brings on no penalty on companion crop yield.

1. Introduction

When two or more crops grow simultaneously in mixture systems, different species inevitably compete for resources, e.g. nutrients and water in the belowground (Andersen et al., 2007; Craine and Dybzinski, 2013; Li et al., 2014; Hu et al., 2017; Li et al., 2017) and light in the aboveground (Zhang et al., 2008; Gou et al., 2016; Yang et al., 2017a,b). The competition is one of the fundamental mechanisms determining the structure and development of plant communities, both in natural ecosystem and agroecosystem (Vandermeer, 1989; van Ruijven and Berendse, 2005; Huang et al., 2017), especially when competition is size-asymmetric (Freckleton and Watkinson, 2001; Chu et al., 2010).

The competition between species is found to be closely related to resource supply and allocation (Craine and Dybzinski, 2013; Hu et al., 2016), plant size (Park et al., 2003), and spatial and temporal arrangements (Xie and Kristensen, 2017; Yang et al., 2017a,b), because these factors affect the initial size of the plant, with an initial size advantage mainly resulting in competitive asymmetry (Schwinning and Weiner, 1998). Size-asymmetric competition has been suggested to be more important than size-symmetric competition in plant growth (Weiner, 1990). A greater advantage in size-asymmetric competition can be gained by the earlier emerging plant (Kropff and Spitters, 1991; Schwinning and Weiner, 1998; Park et al., 2003). Sowing date accounting for different emerging time is the easiest variable for farmers to directly control the management of intercropping system (Tsimba et al., 2013). In a mixture system, if the difference in sowing date between species is larger, a larger size difference occurs between earlier and later emerging plants, resulting in disproportional resource capture

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of soil and light (Benjamin and Hardwick, 1986). Hence, change in sowing date results in temporal niche differentiation and has a meaningful impact on the yield of component crops and system productivity (Willey, 1979a,b; Yu et al., 2015). Such impact is observed in the studies on yam/pumpkin (Olasantan, 2007), okra/cassava (Olasantan and Bello, 2004), and cowpea/millet (Ntare and Williams, 1992) in Africa, and maize/cowpea in Western Australia (Ofori and Stern, 1987). When the cowpea sowing date relative to maize is brought forward, maize yield is significantly reduced while cowpea yield gradually increased, and the largest cowpea yield difference between proper and inferior sowing dates of intercropped maize is 3.4 t ha^{-1} (Ofori and Stern, 1987). In China, there exists a large body of the studies examining the impacts of sowing date on crop performance and final yield, but those studies mostly focus on the performances of the plants in sole and double cropping system (Sun et al., 2007, 2013; Fu et al., 2009) while only limited studies examine the performance in intercropping system (Yang et al., 2017a,b). In one study on maize/soybean intercropping, if the maize is sown later, the intercropped soybean produces less yield and the entire intercropping system also considerably reduces the total productivity (Yang et al., 2017a,b). It is therefore necessary to better understand how sowing date influences plant performance and yield and then to achieve an optimal configuration between sowing dates of different species in intercropping system.

The relative sowing date at a given intercropping pattern has biological and practical effects on the crop growth and yield formation, because it changes the relative competitive ability between intercropped species. The main reason for an imbalance in yield related to sowing date between intercropped species is due to the difference in relative competitive abilities at different relative sowing dates (Park et al., 2003). The competitive ability of one species in a given mixture cropping is closely related to various morphological traits, e.g. canopy height and width, rooting depth and distribution, emergence time, seed/seedling size, growth rate, and growth stage (Park et al., 2003). When a species with an initially slow growth rate is intercropped with a high initial development species, the latter species can achieve normal growth, in most cases, without a reduction in yield because of its high capacity of the interception of light and the capture of other resources (Li et al., 2001a; Sawyer et al., 2010; Gou et al., 2017). This is also the reason why earlier sown species can dominate in an intercropping system. In our previous study of a wheat-maize/watermelon intercropping system in the North China Plain, earlier transplanted watermelon has a significant competition effect on the later sown maize (Huang et al., 2017). When maize emergence is about 40 days later than the watermelon transplanting date, the dense canopy of the watermelon completely covers the maize seedlings, hindering its access to light and other essential resources for normal growth, consequently causing a yield reduction of the intercropped maize relative to the sole maize (Huang et al., 2017).

In most previous studies investigating the impact of the relative sowing date, researchers normally focus on its effect on the final yields of component crops, and little is known about how change in the relative sowing date alters species interactions, especially asymmetric competition caused by temporal management. More importantly, it is relevant for farmers to find an optimal sowing date to enhance the yield of subordinate species without causing a significant yield reduction in companion crop, particularly the valuable crop. Here, we studied a maize/watermelon intercropping system. The key limiting factor for intensification agriculture in this cropping system was the lower yield of the intercropped maize as found in previous studies (Huang et al., 2015, 2017). We hypothesised that properly bringing forward the sowing date of the intercropped maize would reduce the competitive impact on the maize from the intercropped watermelon, and thereby enhance the maize grain yield without causing a reduction in the watermelon fruit yield.

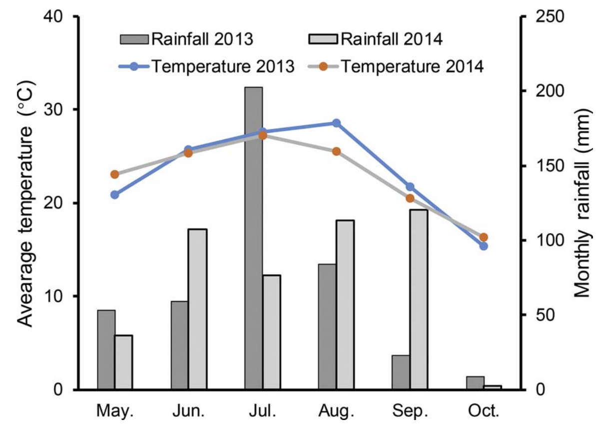

Fig. 1. Monthly mean air temperature and precipitation during the 2013 and 2014 growing seasons.

2. Materials and methods

2.1. Site description

Field experiments were conducted during two consecutive seasons in 2013 and 2014, in the village of Houlaoying (36°39′N, 114°55′E) in the county of Quzhou, Hebei province, in the center of the North China Plain. In and around the village set in a rural area of the North China Plain, there exists a profitable and popular tripartite intercropping system, wheat-maize/watermelon (Huang et al., 2015). The soil at the experiment site consisted of a sandy loam, with a total nitrogen concentration of 0.83 g kg^{-1}, Olsen-P 26.6 mg kg^{-1}, available exchangeable K 168.1 mg kg^{-1} and pH 8.3 (1:5 soil/water). Seasonal rainfall was 377.5 mm in 2013 and 420.9 mm in 2014, and the mean temperature during the growing season was shown in Fig. 1.

2.2. Experimental design and crop management

In the conventional tripartite intercropping system—wheat-maize/watermelon, wheat doesn't significantly affect the growth of watermelon and maize (Huang et al., 2017), so the current study interested specifically in maize/watermelon and examined detailedly how the sowing date of intercropped maize affected interspecific interaction and crop yield. The treatments consisted of three sowing dates for maize: 23 June as control treatment as per local farming practice, 18 June over 5 days and 13 June over 10 days earlier than the control. The field experiment was a randomised block design with three replications implemented in 2013 and 2014. Each treatment consisted of three cropping systems: maize/watermelon intercropping, sole maize and sole watermelon.

The planting patterns of the maize/watermelon were in agreement with the practices of the local farmers (Huang et al., 2015, 2017). In the current study, each plot was 5.4 m wide and 15 m long (81 m^2). The intercrop plot consisted of three alternate strips, each containing three rows of maize and one row of watermelon (Fig. 2C). In the maize strip, two rows of maize were spaced 1.05 m apart on each side of an intercropped watermelon row, with a 0.375 m distance between the watermelon row and the closer row of maize (Fig. 2C). The intra-row distance of maize was 0.3 m, with two plants per hill (Fig. 2C). In general, the planting density of maize was 7.4 plants m^{-2} ($1/([1.05 + 0.375 \times 2]/2 \times 0.3/2)$), and for watermelon it was 0.9 plants m^{-2} ($1/[1.8 \times 0.6]$). The planting patterns of sole maize and watermelon were identical, respectively, with those of intercropped maize (Fig. 2B) and watermelon (Fig. 2A), so the relative densities in intercropped maize and watermelon both were 1.00. The sole maize plot had 9 rows planted with two row distances: 0.75 and 1.05 m, and an intra-row distance of 0.3 m (Fig. 2A). In sole watermelon plot, there were 3