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Effect of aboveground and belowground interactions on the intercrop yields in maize-soybean relay intercropping systems

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ABSTRACT

Aboveground and belowground interactions are crucial in the over-yielding of intercropping systems. However, the relative effects of aboveground and belowground interactions on yields of intercrops in maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] relay intercropping systems are still unclear. Field experiments, including measurements of biomass, grain yield, and photosynthetic parameters, were conducted in 2013–2014 to analyze the advantages and effects of aboveground and belowground of inter-species interactions on yield. To analyze the aboveground interactions of intercrops for light interception, this study adopted three different row configurations [(P1) "160 cm + 40 cm" and (P2) "120 cm + 80 cm" maize wide-narrow row planting, where two rows of soybean with a 40-cm row width were planted in the wide rows, and (P3) "100 cm +100 cm" maize equal-row planting, where one row of maize and one row of soybean with a 50-cm spacing between the adjacent rows of both crops]. Moreover, to identify interspecies belowground competition, no root separation (R1) and root separation (R2) were employed between adjacent maize and soybean rows.

The photosynthetically active radiation (PAR) transmittances of maize wide-row were significantly higher than those of maize narrow-row at the sixth leaf stage (jointing stage), twelfth leaf stage (bell stage), and tasseling stage. Specifically, PAR transmittances decreased as maize narrow-row spacing increased. No significant differences in the PAR transmittances of maize narrow-row or wide-row were found between the R1 and R2 conditions. Similarly, no significant differences between intercrop biomass and grain yield were observed between the R1 and R2 conditions. By contrast, different row configuration treatments exhibited significant differences in biomass (whole growth period for soybean and after tasseling stage for maize), grain yield and photosynthetic parameters of intercrops. These results implied that aboveground interactions, such as mutual shading, have more significant contributions to intercrop advantages than belowground interactions. In addition, the intercropped maize yields increased as maize narrow-row spacing (from P1 to P3 treatment) increased. However, contrasting trends were found for intercropped soybean yield and land equivalent ration (LER). No significant differences in LER were observed between R1 and R2 conditions in different row configurations. P1 treatment exhibited the maximum LER (1.64 for 2013 and 1.83 for 2014) and mixed yield (7430 kg ha^{-1} for 2013 and 9559 kg ha^{-1} for 2014), but the lower maize yield compared with P2 and P3 treatments. This result suggested that reducing the competitive ability of maize while increasing that of soybean significantly improves intercropping advantage in maize-soybean relay intercropping systems.

1. Introduction

Intercropping is the collective planting of two or more crops in the same field (Lithourgidis et al., 2011). Compared with the monoculture cropping system, the intercropping system greatly contributes to crop production through the effective utilization of

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resources (Inal et al., 2007). Intercropping cereals with legumes is commonly implemented in various countries worldwide (Dhima et al., 2007). This cropping system improves soil fertility, reduces weeds and insect pests, and increases yields (Echarte et al., 2011). However, the planting pattern of crops entails the management of space and time in crop production (Liu and Song, 2012). Therefore, we hypothesized that different planting patterns affect crop yields because of the aboveground and belowground interactions among intercropping systems.

Row spacing and intercrop arrangement are important elements of the planting patterns of intercropping systems, can influence the microclimate environment of interspecies, particularly the light transmission rate of crop groups (Liu and Song, 2012; Yang et al., 2014). The wide-narrow row planting pattern has been advocated to increase the advantages of border rows by alternating strips of two different crops (Yang et al., 2014). Liu and Song (2012) showed that the wide-narrow row planting of maize promotes photosynthesis. However, close planting of crops always causes mutual shading among individuals, particularly the mutual shading of narrow-row leaves in intercropping systems, which inevitably depresses leaf photosynthesis (Li et al., 2014b). In intercropping systems, shorter crops suffer shading from taller crops, thus increasing plant height and decreasing yield (Wu et al., 2016). Previous studies on the response of crops to different planting patterns (plant density and row spacing) mainly focus on the morphological characteristics and yield of intercropping (Echarte et al., 2011; Borghi et al., 2012; Yang et al., 2015a,b). However, the effects of interspecies interactions on aboveground light interception and yield by leaf photosynthesis in different row configurations of intercropping systems remain unclear. Some studies have reported the relationship between intercrop photosynthetic parameters and aboveground interactions in a 1:1 proportion of maize to soybean row conditions (Lv et al., 2014), but the effects of different row numbers and row spacing of intercrops on aboveground interactions are not clearly understood.

Therefore, understanding the interspecific belowground interactions between crops is crucial for sustainable grain production (Li et al., 1999). With increasing facilitation and decreasing competition between crops, intercropping systems can use soil water and nutrients more effectively and reduce planting costs, thus improving crop production (Wu et al., 2012). The effect of belowground interactions can be evaluated by separating the roots of intercropped crops (Willey and Reddy, 1981; Lv et al., 2014). Previous studies reported that intercrop productivity may be more affected by belowground than aboveground species interactions in cereal-legume intercropping systems (Ghosh et al., 2009; Lv et al., 2014). However, studies have neglected the importance of spatial-temporal collocation in intercrops for increasing yields and advantages in intercropping systems. Moreover, studies have not considered the effects of varying the distance between intercrop rows and decreasing the symbiotic period of crops on the interspecific belowground interactions.

Maize-soybean relay intercropping is an important type of cereal and legume intercropping (Yang et al., 2014). This intercropping system is widely used in different regions where the growing season is too short for double cropping (Echarte et al., 2011; Coll et al., 2012; Monzon et al., 2014; Yang et al., 2015b). Maize-soybean relay strip intercropping, with a 2:2 maize-to-soybean row ratio, is a common cropping system in the southwestern regions of China (Yang et al., 2014). Previous studies have shown that the interaction between aboveground and/or belowground plant parts was a key factor in intercropping advantage under row intercropping system (the maize-to-soybean row ratio was 1:1) (Lv et al., 2014). However, relay intercropping is different from intercropping in co-existing periods of intercrops, and row configuration play key role in improving intercropping advantage (Mao et al., 2015; Yang et al., 2015b). Up to now, the aboveground and belowground interactions of relay intercropping systems in different row configurations remain unclear. Therefore, understanding the effects of aboveground or belowground interactions on intercrop yield is important to improve crop production management and maintain farm sustainability in maize-soybean relay intercropping conditions.

Table 1
Monthly rainfall and average temperature from March to October in the growing seasons of 2013 and 2014.

Year Month	2013		2014	
	Rainfall (mm)	Average T (°C)	Rainfall (mm)	Average T (°C)
March	15	17	68	12
April	96	18	125	17
May	153	21	113	20
June	182	24	164	22
July	464	25	219	25
August	228	26	430	23
September	212	20	142	21
October	58	18	125	17
March-October	1408	19	1386	20

The present study aims (i) to compare the properties of light environment in maize wide- and narrow-row above-soybean canopy under different row configurations of a maize-soybean relay intercropping system; (ii) to confirm which interaction (aboveground or belowground) affects intercrop yield by different row configurations and root separation of intercropped crops in relay intercropping systems; and (iii) to further analyze the effect of interspecific or intraspecific mutual shading of aboveground crops on total biomass and grain yield by measuring the photosynthetic parameters of the two intercrops.

2. Materials and methods

2.1. Experimental location

Experiments were conducted from 2013 to 2014 at the experimental farm of Sichuan Agricultural University in Ya'an, Sichuan Province, China (30°08′N, 103°00′E, 620 −m elevation). The climate of the experimental site was subtropical and humid. The precipitation amount and air temperature during the intercropping growth seasons from 2013 to 2014 are presented in Table 1. The soil has a clay loam texture with 7.2 pH, 27.5 g kg^{-1} organic matter, 0.41 g kg^{-1} total N, 0.52 g kg^{-1} total P, 6.03 g kg^{-1} total K, 53.1 mg kg^{-1} available N, 15.7 mg kg^{-1} available P, and 107.9 mg kg^{-1} available K in the 0–20 cm soil layer.

2.2. Experimental design and treatments

A maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] relay intercropping system was used in the field experiments. The intercropping patterns utilized wide-narrow row planting with alternating strips of maize and soybean. Different row planting patterns were adopted to analyze the aboveground interactions of intercrops for capturing more light. The three row configuration treatments were as follows: (P1) "160 cm + 40 cm" maize wide-narrow row planting, i.e., the relay intercropping combination of two crop strips with a total width of 200 cm, consisting of two rows of maize and two rows of soybean with 40-cm row width for maize and soybean, and 60-cm spacing between adjacent rows of maize and soybean; (P2) "120 cm + 80 cm" maize wide-narrow row planting, i.e., 80-cm and 40-cm row width for maize and soybean, respectively, and 40-cm spacing between the adjacent rows of maize and soybean; (P3) "100 cm +100 cm" maize equal row