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# Changes in light environment, morphology, growth and yield of soybean in maize-soybean intercropping systems

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ABSTRACT

The maize-soybean intercropping system has become increasingly popular in many areas of the world, particularly in China, due to its high productivity and the harvest of two different grains. While efforts have been made to maintain the yield of the taller maize crop, there is limited understanding of how the morphology, growth and yield of the lower soybean crop changes in response to the shading by maize. We therefore conducted a three-year field experiment from 2013 to 2015 to investigate the changes in light environment, growth of individual organs, biomass, and grain yield of soybean under two intercropping patterns (1M1S, one row of maize with one row of soybean; 2M2S, two rows of maize with two rows of soybean) as compared to monoculture. Our results showed that at soybean flowering stage, the R:FR ratio at the top of soybean canopy was reduced 17–21% more than the photosynthetically active radiation (PAR) under intercropping compared to monoculture, with 15–19% more reduction under 1M1S than 2M2S. This led to increased internode lengths, plant height and specific leaf area (SLA), but reduced branching of soybean plants under intercropping. These morphological changes enabled the crop to intercept relatively more light and the shading also increased the light use efficiency (LUE) of soybean. However, these positive responses were not able to compensate the effect of reduced leaf area (due to smaller leaf size and less branching) and total light interception, leading to reduced biomass and grain. The reduction in grain yield was mainly caused by the reduced number of grains (particularly on the middle nodes) produced by the intercropped soybean plants, while the grain size remained unchanged. The data and results of this study may be used to develop and parameterize crop models for simulating development and growth of soybean crop in response to changes in the light environment under intercropping.


## 1. Introduction

Intercropping enhances resource use efficiency (Mao et al., 2012; Coll et al., 2012), and has been widely practiced in many developing countries (Li et al., 2007; Rodriguez-Navarro et al., 2011). Intercropping systems provide 15–20% of the world's food supply (Lithourgidis et al., 2011). Maize and soybean intercropping is a popular system in South America (Echarte et al., 2011), Africa (Oseni, 2010; Undie et al., 2012) and Asia (Lv et al., 2014). In such systems, the land equivalent ratio (LER) was more than 1.3 (Undie et al., 2012; Mahallati et al., 2014), that is, one hectare of land under intercropping can produce the same crop yield as 1.3 ha of land under monoculture.

Recently, maize-soybean strip intercropping is being practiced on approximately 667 thousand hectares of land in southwestern China and the area is still growing due to increasing demand for protein rich foods (Yan et al., 2010; Yang et al., 2014). Two rows of maize intercropped with two rows of soybean were previously applied (Yang et al., 2015; Rahman et al., 2016). In these systems, the plant distance in a row was smaller than that in the monoculture in order to keep the same planting density of maize as in monoculture. Thus, the yield of intercropped maize was close to the monoculture due to border row effect and the same planting density. The LER in these relay strip intercropping systems were more

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than 1.8. However, there is limited data available to our knowledge on how the morphology, growth and grain yield of soybean changes in such intercropping systems.

In the maize-soybean intercropping system, the shading by the taller maize crop modifies the light environment experienced by the lower soybean crop in terms of both light quantity (PAR-photosynthetically active radiation) and quality (R:FR ratio). These changes are affected by the intercropping configuration and crop architecture (Tsubo and Walker, 2002; Zhang et al., 2008; Munz et al., 2014), and causes changes in both morphology and growth of the soybean crop. Morphological changes could include changes in internode lengths, plant heights, leaf sizes, and branching (Page et al., 2011; Yang et al., 2014; Gong et al., 2015). Growth changes could include changes in light use efficiency (LUE), growth rate and harvest index (Awal et al., 2006; Forster et al., 2007; Li et al., 2008; Zhang et al., 2008; Gao et al., 2010). Detailed data are needed to quantify such changes in order to understand how the lower soybean crop maximizes its efficiency to use the light resources and maintain yield.

The objectives of this study therefore were to: (1) quantify the changes in light intensity and quality (R:FR ratio) at the canopy of intercropped soybean under the shading of maize in two intercropping patterns; (2) analyze the morphological changes of soybean crop in response to light environment change; (3) study the causes for the reduction in crop dry matter and yield of soybean in response to the shading effect; (4) explore how these changes maximize the use of the light resource of soybean.

## 2. Materials and methods

### 2.1. Field experiments

Field experiments were conducted in 2013, 2014 and 2015 at a location in Heze City (35°15′09″N, 115°25′05″E), Shandong province, China. The site was characterized as a temperate continental monsoon climate. The weather data during the crop growing season each year were obtained from Heze Meteorological Bureau (Table 1). The soil in the study field has a clay texture, with a bulk density of 1.24 g $m^{-3}$, and the available N, P and K in the top soil profile (0–30 cm) of 101,34,187 mg $kg^{-1}$, respectively at the start of this experiment.

A three-year experiment was conducted by randomized complete block design with three treatments and three replicates. The treatments were: (1) one row of maize alternated with one row of soybean (1M1S); (2) two rows of maize alternated with two rows of soybean (2M2S), and (3) soybean monoculture (Mono) (Fig. 1). For 2M2S, the whole intercropping strip width was 2 m, the row spacing between maize and soybean rows was 0.4 m, and the distance between adjacent maize and soybean rows was 0.6 m. For 1M1S, the whole intercropping strip width was 1 m and the distance between adjacent maize and soybean rows was 0.5 m. The distance between two adjacent maize plants and two adjacent soybean plants in a row was 0.14 m and 0.07 m, respectively. For soybean monoculture, the distance between two rows was 0.5 m. The plant distance in a row was 0.07 m for soybean in monoculture. The planting density for soybean in intercropping was 50% of that in monoculture, while the planting density for maize was the same in 1M1S and 2M2S. The plot size was (6 × 6 $m^2$) including 3 soybean strips (6 rows) in 2M2S and 6 strips (rows) in 1M1S. Maize cultivar 'Xundan 26' and soybean cultivar 'Hedou 19' were used in all three years from 2013 to 2015.

Maize and soybean in both intercropping and monoculture were planted and harvested on same days. Sowing time was June 13, 2013, June 10, 2014 and June 14, 2015. Harvesting time was September 26, 2013 and September 28, 2014 and 2015. Three irrigations each with 33.3 mm of water were applied by sprinklers in three growing seasons on June 18, 28 and July 31 in 2013; June 20, 27 and July 12 in 2014 and June 20, July 5, and July 21 in 2015. Weeds and pest were properly controlled according to typical farmers' practices. N at the rate of 150 kg $ha^{-1}$, P at 100 kg $ha^{-1}$ and K at 100 kg $ha^{-1}$ were broadcasted once in the middle of July in the intercropping and there was no fertilizer applied for soybean monoculture.

### 2.2. Measurements

Photosynthetically active radiation (PAR) and red:far-red ratio (R:FR) were measured at the top of soybean and maize canopy (Fig. 1) using a LI-191SA quantum sensor (LI COR Inc., 114 Lincoln, NE, USA) for PAR and a fiber-optic spectrometer (AvaSpec-2048; Avantes, Netherlands) for R:FR. Diurnal course of PAR was measured every two hours on a sunny day from 7:00 to 19:00 at 70 days after sowing (DAS). Seasonal courses of PAR and R:FR were measured at noon on sunny days every 10–20 days.

The final sizes of internodes and leaves, stem diameters and final plant height for soybean were measured by sampling 10 plants. The final leaf size was measured at 45 DAS for the leaves located on the first three stem nodes and 85 DAS for the other leaves. Internode length, stem diameter and plant height were measured at harvest. The first internode was used to measure stem diameter. The number of soybean branches were counted with 100 plants per plot at harvest time.

The appearance and termination dates of soybean phytomers, nodes and leaves were observed by tagging 5 plants per plot. Thermal time (TT) was used to measure the duration of organs. The thermal timeas growing degree days for soybean was calculated by summing average air temperature above a base value of 10 °C (Holmberg, 1973; Major et al., 1975) during the growing seasons. The phytomer number, as the same as node and leaf numbers, was counted from the first true leaf (Zhu et al., 2014). The serial number of phytomer for branches was the number of the inserted branch at the main stem plus the phytomer number for this branch, for example, 7 for 2nd node at 1st branch at 5th node of main stem. The termination date was determined when the internode length increased less than 0.1 cm within three days.

The leaf area and dry matter per plant were measured every 10–15 days. Ten soybean plants in each plot were destructively sampled with at least 0.5 m away from previous sampling area. Border rows of a plot were avoided in the sampling. The area of a single leaf was determined by multiplying leaf length, maximal width and a shape coefficient factor of 0.75 (Gao et al., 2010). And then, the samples were weighed after dried to constant mass (48 h) at 80 °C in a drying oven. Specific leaf area (SLA) was calculated by leaf area (mixed all leaves together) and dry matter of leaves at 50 DAS (flowering stage).

The soybean yield was measured in a 4 $m^2$ sampling area in each plot at harvest time. Border rows of a plot were avoided in the sampling. These samples were also for the measurement of grain number per plant and 100 grain weight. For grain number per plant, 10 plants of soybean were randomly selected from the samples. Soybean grains were sun-dried to a water content of 12%. Finally, the harvest index (HI) was determined using the yield and dry matter of 10 soybean plants.

### 2.3. Calculation of light interception and light use efficiency (LUE) of soybean

The light intercepted fraction for the intercropped soybean was calculated by two different models in 1M1S (Gao et al., 2010) and 2M2S (Wang et al., 2015). The model for intercropping system with horizontally homogeneous leaf area (HHLA) was used to calcu-