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Growth of soybean seedlings in relay strip intercropping systems in relation to light quantity and red:far-red ratio

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ABSTRACT

Maize–soybean intercropping is a common system in several countries. However, different spatial patterns of maize and soybean can directly affect the light environment of soybean growth under this system through the combined effects of the altered light quality and the reduced light quanta. This work aimed to investigate the differences in the light environment of the soybean canopy in terms of the red:far-red (R/FR) ratio and the photosynthetically active radiation (PAR) as well as the different rates of soybean seedling growth under maize–soybean relay strip intercropping and soybean sole planting, to analyze the relationship between the morphological characteristics and the light environment, and to assess the relative contributions of the R/FR ratio and PAR transmittance to soybean seedling growth in intercropping conditions.

Field experiments were performed in 2011–2013. The intercropping patterns involved the wide-narrow row planting of alternating maize and soybean. The light environment of the soybean canopy and the morphology of the soybean seedlings were estimated in the relay strip intercropping system by changing the distances of the maize and soybean rows as well as the number of maize *vs.* soybean rows per strip. These parameters of the intercropping system were compared with those of the soybean monocultures. Furthermore, the relationship between the light environment of the soybean canopy and its morphological parameters were analyzed using correlation analysis.

Incident light in maize–soybean relay strip intercropping systems was partly reflected and absorbed by maize leaves. Thus, the spectral irradiance, R/FR ratio, and PAR of the soybean canopy were decreased with maize–soybean intercropping as compared to soybean monocropping. Simultaneously, the stem diameter, root length, aboveground biomass, total root biomass, and root–shoot ratio of relay intercropped soybean were reduced significantly, while its seedling height was increased. The correlation relationship between morphological parameters of soybean and the light environment (R/FR ratio and PAR transmittance) in different planting pattern were significant ($P < 0.05$). Compared to PAR transmittance, the R/FR ratio of the relay intercropped soybean canopy was strongly correlated with morphological parameters of soybean seedling ($P < 0.01$), and the correlation coefficients were higher than 0.88. The response of soybean seedlings to shading by maize was not solely influenced by the PAR or the R/FR ratio. It may be the summed effects of both parameters under relay strip intercropping systems. Therefore, the results reveal the physiological response mechanisms of soybean seedlings to changes in the quality and amount of light, which may support the building three-dimensional growth model of the responses of plant to light quantity and quality, and guide the identification of suitable population planting patterns in the intercropping system in the future.

1. Introduction

The amount of cultivable land is gradually decreasing because of the rapid urbanization and industrialization caused by the global population explosion (Awal et al., 2006). The demand for food is ever-increasing with the increasing population. Consequently, increasing the multiple crop index of land is particularly important for the development of grain production (Yan et al., 2010).

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Relay cropping and intercropping are important in subsistence and food production worldwide (Ofori and Stern, 1987; Rodriguez-Navarro et al., 2011). These planting patterns often outyield their sole crop components because of the more efficient use of resources as well as the reduced incidence of weeds, insect pests, and diseases (Caviglia et al., 2004; Echarte et al., 2011).

The combination of partner crops in intercropping systems depends mainly on the crop geometry, but the growth habit, life span, and management practices of the crops likewise influence this combination (Connolly et al., 2001; Awal et al., 2006). Cereal and legume intercropping is recognized as a common cropping system in several countries (Ofori and Stern, 1987). In China, half of the total grain yield is produced with multiple cropping, maize–soybean relay strip intercropping systems in particular (Fig. 1) are one of major planting patterns in the southwestern regions (Yan et al., 2010; Zhang et al., 2011).

The maize in maize–soybean relay strip intercropping systems is usually sown according to the narrow-wide row planting pattern at the end of March or the beginning of April and harvested at the end of July or the beginning of August. Soybean is sown in the wide rows between maize at the beginning of June and harvested at the end of October. The seedling phase of soybean and the reproductive phase of maize overlap over a period of approximately eight weeks between the sowing of soybean and the harvesting of maize. Thus, the two different crop species can be grown during one season in production areas where the growing season is too short for double cropping. This system increases the productivity as it takes advantage of the biological N fixation by soybean, thereby reducing the demand for N-containing fertilizers (Stern, 1993). Aside from nutrient acquisition, the additional components such as the border row effects contribute to the overyielding of intercropped maize (Knörzer et al., 2009).

The planting patterns of maize-soybean intercropping systems can induce changes in the microclimate environment within the crop canopy, particularly in the light intensity and the spectral properties of the soybean canopy with its lower layer (Awal et al., 2006). Soybean is highly sensitive to shading (Wolff and Coltman, 1989). Thus, when grown with maize shading under this system, soybean seedlings have increased height and thinner stems that are easier to lodge. Therefore, an analysis of the relationships between the light environment and the morphological characteristics of relay intercropped soybean is important to build three-dimensional growth model and determine the suitable population pattern and parameters in the future.

The light quality, which is measured by the red:far-red (R/FR) ratio, and the light quanta, which is represented as the photosynthetically active radiation (PAR), are two main light properties in shaded environments that can modify plant growth and development (Smith, 2000). Light that has passed through a canopy is rich in FR light but poor in R light (Evers et al., 2006). Chlorophyll depletes R light, whereas FR light is predominantly reflected and transmitted by the pigment (Vandenbussche et al., 2005). Plants that can detect a low R/FR ratio will initiate a series of physiological changes and consequently express shade avoidance characteristics such as increased stem elongation, reduced stem diameter, and decreased root biomass (Page et al., 2010; Afifi and Swanton, 2011). Similarly, the reduction of crop plant productivity can be induced by these changes in light quality (Ruberti et al., 2012). Kasperbauer and Karlen (1986) reported that wheat seedlings exposed to FR had higher shoot/root ratios than unshaded plants. Pecháčková (1999) found that a reduced R/FR ratio decreased the root biomass of a rhizomatous grass species.

Most of the literature has confirmed the trend of changes in the plant height, stem diameter, root biomass, and aboveground biomass under low R/FR ratios or shade stress conditions (Kasperbauer and Karlen, 1986; Pecháčková, 1999; Page et al., 2010; Afifi and Swanton, 2011; Ruberti et al., 2012). However, these studies only explained the morphological changes under shading conditions or low R/FR ratios. The effect of the light environment on crop growth under intercropping systems with different spatial patterns was not considered. The relationship between the morphological parameters and the light environment (PAR or R/FR ratio) in intercropping systems was not addressed in these studies. Likewise, the parameters that were sensitive to the shading environment were not identified. Relatively little research has focused on effects of maize shading on soybean seedling growth (Zhang et al., 2011).

This paper reports the different responses of soybean seedling growth to the changing light environment (represented by variations in the PAR and R/FR ratio) that is caused by maize in the relay strip intercropping system. The objectives of this study were: (i) to compare the properties of the light environment in the soybean canopy for soybean sole cropping and maize–soybean relay strip intercropping systems; (ii) to investigate the different morphological parameters of soybean under two planting systems; and finally, (iii) to analyze the relationships between the morphological characteristics and the light environment for assessing the relative contributions of light quality (R/FR ratio) and light quanta (PAR transmittance) to soybean seedling growth in intercropping system.

2. Materials and methods

2.1. Study site and experimental design

Experiments were conducted from 2011 to 2013, fields were assigned to different treatments in a randomized block design with three replications in the same field at the farm of the Sichuan Agricultural University in Ya'an, Sichuan Province, China (29°59′ N, 103°00′ E). The field climate was subtropical humid, with a mean annual temperature of 16.2 °C and a mean annual rainfall of 1200 mm.

2.1.1. Experiment 1

This experiment was conducted in 2011, with two treatments each for the maize–soybean relay intercropping and the soybean monoculture. The soybean (*Glycine max* L. Merr.) cultivars Gongxuan1 and Nandou12, and the maize (*Zea mays* L.) cultivar Chuandan418 are major southwestern cultivars. The intercropping patterns used wide-narrow row planting, with alternating strips of maize and soybean. The number of maize *vs.* soybean rows per strip in the relay strip intercropping systems was 2:2. The distance between the maize and soybean strips was 60 cm, and both row spaces were 40 cm under strip intercropping. The row space of the soybean monoculture was 70 cm (Fig. 2). The experimental unit was 6 m long and 12 rows wide for intercrops and 6 m long and 10 rows wide for sole crops. Maize was sown on 25 March 2011, whereas soybean was sown on 15 June 2011 when the maize plants were at the V12 stage. The plant densities of relay intercropped maize, monocultured soybean, and relay intercropped soybean were 6, 10, and 10 plants m^{-2}, respectively. All plots were treated with basal fertilizers. Before sowing, basal N at 44 kg ha^{-1} as urea, P at 40 kg ha^{-1} as calcium superphosphate, and K at 10 kg ha^{-1} as potassium sulfate were applied to all plots. At the V6 stage of maize, N at 165 kg ha^{-1} as urea was applied for the relay intercropped maize.

2.1.2. Experiment 2

According to the interesting results of light environment change in experiment 1, the experiment 2 was conducted and was comprised of seven cropping systems with maize (*Z. mays* L.) and soybean (*G. max* L. Merr.) in 2012–2013 for estimating the relationship of morphological characteristics with PAR transmittance and