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RESEARCH ARTICLE

Shade adaptive response and yield analysis of different soybean genotypes in relay intercropping systems

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Abstract

Soybean is one of the major oil seed crops, which is usually intercropped with other crops to increase soybean production area and yield. However, soybean is highly sensitive to shading. It is unclear if soybean morphology responds to shading (i.e., shade tolerance or avoidance) and which features may be suitable as screening materials in relay strip intercropping. Therefore, in this study, various agronomic characteristics of different soybean genotypes were analyzed under relay intercropping conditions. The soybean materials used in this study exhibited genetic diversity, and the coefficient of variations of the agronomic parameters ranged from 13.84 to 72.08% during the shade period and from 6.44 to 52.49% during the maturity period. The ratios of shading to full irradiance in stem mass fraction (SMF) were almost greater than 1, whereas opposite results were found in the leaves. Compared with full irradiance, the average stem length (SL), leaf area ratio (LAR) and specific leaf area (SLA) for the two years (2013 and 2014) increased by 0.78, 0.47 and 0.65 under shady conditions, respectively. However, the stem diameter (SD), total biomass (TB), leaf area (LA), number of nodes (NN) on the main stem, and number of branches (BN) all decreased. During the shady period, the SL and SMF exhibited a significant negative correlation with yield, and the SD exhibited a significant positive correlation with yield. The correlation between the soybean yield and agronomic parameters during the mature period, except for SL, the first pod height (FPH), 100-seed weight (100-SW), and reproductive growth period (RGP), were significant ($P<0.01$), especially for seed weight per branch (SWB), pods per plant (PP), BN, and vegetative growth period (VGP). These results provide an insight into screening the shade tolerance of soybean varieties and can be useful in targeted breeding programs of relay intercropped soybeans.

Keywords: intercropping, light, morphological parameters, shade avoidance, soybean

1. Introduction

Soybean (*Glycine max* (L.) Merr.) is one of the major oilseed crops that is produced and consumed for protein and oil throughout the world (Tacarindua *et al*. 2013). It has been planted as a sole crop and for intercropping in various continents worldwide, such as in Asia, Africa and Latin America

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(Andrade *et al*. 2012; Ijoyah *et al*. 2013; Yang *et al*. 2014). Intercropping has the important role of increasing soybean yield for economic development and the reduction of arable land (Yang *et al*. 2014). It involves the collective planting of two or more crop species in the same field (Lithourgidis *et al*. 2011). It has been reported that intercropped soybeans play a key function in reducing the demand for N-containing fertilizers and increasing the soybean yield and planting areas while not affecting the production of adjacent crops (Yang *et al*. 2015).

Soybean is intercropped with various crops, such as maize, sorghum, sunflower, and fruit trees, to increase its productivity (Ghosh *et al*. 2009; Manceur *et al*. 2009; Zhou *et al*. 2009; Echarte *et al*. 2011; Yang *et al*. 2014). However, soybean is highly sensitive to shading, and it receives altered light when grown under canopy shade or the shade of neighboring taller crops (Smith 2000). However, light is a significant resource for photoautotrophic higher plants that affects their survival and growth (Huang *et al*. 2011). Thus, plant growth and developmental processes can be altered by shading (Kurepin *et al*. 2012).

Plants that can detect low light initiate a series of morphological changes and consequently express shade avoidance characteristics, such as increased stem elongation, reduced stem diameter, and foliage number (Skálová 2005; Page *et al*. 2010). Similarly, a reduction in crop productivity can be induced by these changes (Ruberti *et al*. 2012). Thus, plants must invest more mass in their stems to acquire high-light conditions and the maximum rates of photosynthesis (Vermeulen *et al*. 2009).

To acclimate to shade, plants often exhibit remarkable shade avoidance by investing more mass in their stems and, therefore, relatively less mass in their leaves, which then tend to have a lower area per unit mass (Corré 1983; Vermeulen *et al*. 2009). The leaf area ratio (LAR) is the main factor that explains the variation in the growth rate of different plants (Poorter and Rose 2005). The specific leaf area (SLA) is another important trait that regulates and controls plant functions, such as carbon assimilation and carbon allocation (Feng *et al*. 2007). When exposed to shade, plants optimize light capture and utilization by increasing their SLA (Evans and Poorter 2001). Generally, plant SLA and LAR decrease with an increase in irradiance under shady conditions (Feng *et al*. 2004). Until now, no specific parameters is available to evaluate the shade avoidance of soybeans in intercropping agricultural ecosystems.

A substantial amount of research studies have focused on the ecology and ecophysiology of tree species under shady conditions (Skálová 2005; Paquette *et al*. 2007; Vermeulen *et al*. 2009; Page *et al*. 2010; Gommers *et al*. 2013). However, few studies have addressed the shade avoidance response of soybeans for variety selection in intercropping agricultural ecosystems. Therefore, the development of special acclimation and plasticity mechanisms so that soybean can cope with different light conditions should be considered in targeting breeding programs for intercropping agricultural ecosystems.

Under intercropping conditions, different planting patterns resulting in different light environments of the soybean canopy that affect the soybean yield (Yang *et al*. 2015). The plant structure, number of branches, and growth period are closely related to the soybean yield (Ao *et al*. 2013). Few research studies have focused on the relationship between the branch traits and soybean yield (Liu *et al*. 2014).

In this context, the main objectives of this study were as follows: (1) to elucidate the trade-offs of the photoassimilated distribution of different soybean genotypes under shady conditions, (2) to determine whether the shade adaptive response of soybean is a form of tolerance or avoidance based on its morphological parameters in intercropping systems, and (3) to analyze the relationship between the agronomic parameters and soybean yield for screening or breeding suitable genotypes in intercropping systems.

2. Materials and methods

2.1. Experimental site

Experiments were conducted at the Ya'an experimental farm of Sichuan Agricultural University, China during 2013–2014. The field climate was subtropical and humid. The soil consisted of purple clay loam. The precipitation rates and air temperature during the soybean growth seasons at the experimental site were provided in a previous study (Yang *et al*. 2014).

2.2. Experimental materials

In 2013, a total of 131 soybean genotypes were used as the experimental material. The genotypes of 129 soybeans were obtained from 13 regions in China, particularly from the southern and Huang-Huai River Valley of China where intercropping is typically practiced (Knörzer *et al*. 2009; Fig. 1). The four other genotypes were obtained from Japan, Australia and Vietnam. In 2014, 14 soybean genotypes of different shade adaptabilities were chosen as the experimental materials (based on biomass, stem length during the shade period, and seed weight per plant during the mature period in 2013; Appendix A).

2.3. Experimental design

In 2013, the shading for the experiment was provided by a green polypropylene fabric that was installed 2 m above the soil surface. The shade cloth (resulting in 60% light reduc-