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Crop yield, nitrogen acquisition and sugarcane quality as affected by interspecific competition and nitrogen application

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ABSTRACT

While economic efficiency of sugarcane (*Saccharum sinensis* Roxb)–legume intercropping has attracted a lot of attention around the world, interspecific competition between sugarcane and legume has not been studied so far. A three-year (2009–2011) field experiment was conducted by using a randomized block design with two N application levels (N1, 300 kg hm^{-2} and N2, 525 kg hm^{-2}) and four crop arrangement patterns (soybean monoculture, sugarcane monoculture, 1:1 row sugarcane–soybean intercropping, 1:2 row sugarcane–soybean intercropping). The crop yield and nitrogen acquisition of sugarcane and soybean, and quality of sugarcane juice were determined at the maturity stages of soybean or sugarcane. Land equivalent ratio (LER) was used to evaluate the potential advantages of the intercrops, aggressivity (AG), and competitive ratio (CR) which based on crop yield and nitrogen acquisition were used to evaluate interspecific competition between sugarcane and soybean. The results indicated that sugarcane–soybean intercropping system had intercropping advantages based on total LER in the three-year. Sugarcane had lower AG and CR values than soybean. The quality of sugarcane juice was not significantly different between intercropping and monoculture, except the excessive nitrogen application (N2) in 2011, which reduced the apparent purity and gravity of sugarcane juice significantly compared with normal nitrogen application (N1). This paper suggests that the intercropping advantage of sugarcane–soybean system is mainly contributed by soybean. The introduction of soybean in a sugarcane field does not significantly affect the quality of sugarcane juice.

1. Introduction

Cereal–legume intercropping systems have several major advantages in increasing yield, land use efficiency (Ghosh, 2004; Dhima et al., 2007), efficiency in utilization of natural resources including light, water, and nutrients (Harris et al., 1987; Zhang and Li, 2003; Xu et al., 2008), and in controlling pests and diseases (Berry et al., 2009; Li et al., 2009; Chen et al., 2011). Cereal–legume intercropping system has become a common cropping system around the world (Jensen, 1996; Li et al., 2001; Lithourgidis et al., 2011; Eskanddari, 2012).

As a cereal crop, sugarcane is a major crop for sugar and biofuel in the world (Robinson et al., 2011). Both wide row spacing (90–150 cm) and slow growth rate in the initial stage of sugarcane provide space and resources (water, nutrition, light) niche for intercropping in sugarcane field. Many studies demonstrate sugarcane interplanted with crops such as watermelon (*citrus vulgaris* var. Caliber), peas (*Pisum sativum*), onions (*allium cepa*) and so on would reduce sugarcane yield, yet increase economic income considerably (Nazir et al., 2002; Gana and Busari, 2003; Al Azad and Alam, 2004). However, both sugarcane yield and net income increased in sugarcane–potato (*Solanum tuberosum cv.* Kufri Bahar) intercropping system (Imam et al., 1990; Singh et al., 2010). Control of pests including diseases, insects, and weeds in sugarcane intercropping system were also studied (Singh and Lal, 2008; Berry et al., 2009; Li et al., 2009; Chen et al., 2011). However, there is a lack of information on assessing interspecific competition in sugarcane intercropping systems so far.

Competition is one of the major factors that have significant impact on the yield advantage of intercropping systems (Caballero et al., 1995; Li et al., 2011). When inter-species competition in an intercropping system is lower than intra-species competition, result of higher yields has been reported (Vandermeer, 1990). In order to assess the ability of interspecific competition in an intercropping system, several indices such as AG (aggressivity) and CR

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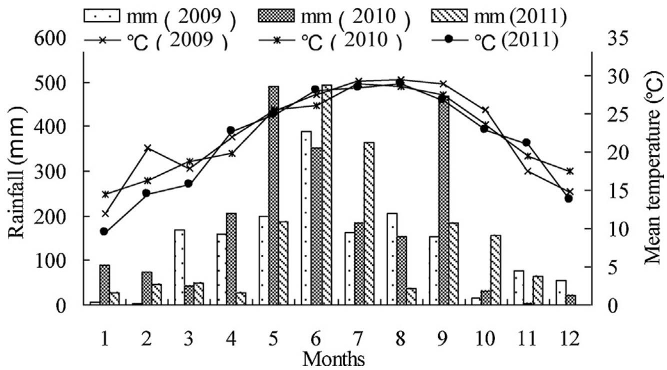

Fig. 1. Monthly rainfall and mean temperature during 2009–2011 in Guangzhou.

(competitive ratio) have been developed to describe interspecific competition within intercropping (Dhima et al., 2007; Corre-Hellou et al., 2011). LER (land equivalent ratio) has been employed to evaluate the yield advantage in sugarcane–(maize or potato) intercropping systems (Govinden, 1990; Li et al., 2009). These indices have not been used to assess the interspecific competition within sugarcane–soybean intercropping systems yet.

A continuous three-year field experiment was conducted to explore the yield and quality of sugarcane, and interspecific competition in sugarcane–soybean intercropping systems. Soybean could be considered as an added crop to the wide row spacing mono-sugarcane field.

We hypothesized that the additive crop could influence competitive ability and quality of component crop and yield of the intercropping system. The objectives of this study were: (a) to estimate the intercropping advantage of sugarcane intercropped with soybean, (b) to assess interspecific competition with the different competitiveness indices, and (c) to examine the quality of sugarcane quality under intercropping systems and two rates of nitrogen application.

2. Materials and methods

2.1. Field sites

The field experiment was conducted in 2009–2011 in the farm of South China Agricultural University, Guangzhou China (23°8′ N, 113°15′ E) where tropical ocean monsoon climate prevails with average 1780 h annual sunshine time. The soil of the experimental field is a latosolic red soil with 21.08 g kg^{-1} organic matter, 75.38 mg kg^{-1} available N, 75.04 mg kg^{-1} Olsen P and 61.71 mg kg^{-1} K in the upper 30 cm. Meteorological data were collected in Wushan Weather Station, Guangzhou (Fig. 1).

2.2. Experiment design

Randomized complete block design with three replications were adopted for the experiment design. The cropping systems were arranged in the main plots whereas nitrogen rates and cropping ratio of the two crops were arranged in the subplots. The cropping systems including mono sugarcane (MS), mono soybean (MB) and sugarcane–soybean intercropping (SB1, SB2); nitrogen rates were two levels, 525 kg hm^{-2} as conventional nitrogen application level (N2) used by local farmers, and 300 kg hm^{-2} as a reduced nitrogen application rate (N1) (see Table 1).

Plot size was 5.5 m × 4.8 m (Fig. 2) and the planting distance of sugarcane and soybean in the same row were 1.2 m and 0.3 m in all treatments, respectively. In sugarcane–soybean intercropping, there were four rows of sugarcane and four (MS1) or eight (MS2) rows of soybean in each plot. In MS and MB systems, there were 4 rows of sugarcane or 16 rows of soybean in each plot, respectively.

According to the actual weather situation each year, sugarcane was sown on 20 February 2009, 15 March 2010 and 26 February 2011 and soybean was sown on 21 February 2009, 16 March 2010 and 2 March 2011. The sugarcane cultivar 'Yuetang 00-236' was used. Soybean cultivar was 'Maodou No. 3'. The soybean crops were harvested on 21 May 2009, 20 June 2010 and 2 June 2011 respectively. The sugarcane crops were harvested on 10 January 2010, 26 December 2010 and 18 December 2011 respectively. Basal fertilizer included potassium chloride 150 kg hm^{-2}, calcium superphosphate 1050 kg hm^{-2}, and compound fertilizer (N:P:K = 15:15:15) 750 kg hm^{-2} were applied before the sugarcane was planted. The first topdressing fertilizer included 150 kg hm^{-2} potassium chloride, and 225 kg hm^{-2} or 113 kg hm^{-2} urea under N2 or N1, respectively, was applied when sugarcane was at tillering stage. The second topdressing fertilizer with 672 kg hm^{-2} or 295 kg hm^{-2} urea under N2 or N1, respectively, was applied at the sugarcane jointing stage. The fertilizer application was the same through 2009 to 2011.

2.3. Sampling and analytical methods

2.3.1. Sample collection

Plant samples were collected at two stages including the first stage at the maturity of soybean and the second stage at the maturity of sugarcane. The soybean yields were measured by collecting all soybean pods in the third rows of the intercropping systems (SB1, SB2) and collected all soybean pods in one of the middle rows in the mono soybean systems (MB). The sugarcane yields were measured by cutting all stalks in the third row in the plots. For measuring total crop biomass, three plants including cane and above ground vegetative organ in each plot were sampled at random in the third row during harvesting stage. The stalks were cut into small pieces and dried in an oven at 105 °C for 30 min, and then at 80 °C until a constant weight was reached, then dry weight was recorded (Tejera et al., 2007). Dried plant samples were milled and stored in small bags. Total N concentrations of plant samples were determined by Kjeldahl digestion (KDY 9810, Kaihong Weiye Science, Beijing).

2.3.2. Sugarcane juice quality

Six sugarcane stalks were crushed using a cane crusher TJ-305 (Chaozhou First Agricultural Machinery Plant, Guangdong, China) and sugarcane juice was collected. The Pol reading and sucrose content of the juice were measured by a WZZ-2S Automatic polarimeter (Shanghai Precision & Scientific Instrument Co., Ltd., Shanghai, China). The sugar Brix was tested by Refractometer PAL-1 (ATAGO Co., Ltd., Tokyo, Japan). The juice apparent purity, gravity purity sugarcane fiber content, and sucrose content were calculated by Sugar 2000 software (Guangzhou Sugarcane Industry Research Institute, Guangdong, China).

Table 1
Field experiment design of sugarcane–soybean intercropping.

Cropping systems	Nitrogen rate (kg hm^{-2})	Cropping patterns
MS-N1	300	Mono sugarcane
SB1-N1	300	Sugarcane–soybean (1:1)
SB2-N1	300	Sugarcane–soybean (1:2)
MB	0	Mono soybean
MS-N2	525	Mono sugarcane
SB1-N2	525	Sugarcane–soybean (1:1)
SB2-N2	525	Sugarcane–soybean (1:2)