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ORIGINAL PAPER

Effects of intercropping sugarcane and soybean on growth, rhizosphere soil microbes, nitrogen and phosphorus availability

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Abstract The effects of sugarcane plantation intercropped with soybean on plant growth, yield, enzyme activity, nitrogen and phosphorus contents, the microbe quantity of rhizosphere soil were investigated. Results showed that dry weight of biomass and yield under sugarcane/soybean intercropping were increased by 35.44 and 30.57 % for sugarcane, and decreased by 16.12 and 9.53 % (100-grain weight) for soybean, respectively. The nitrogenase activity of intercropping soybean nodule was significantly increased by 57.4 % as compared with that in monoculture models. The urease activities of intercrops sugarcane and soybean were promoted by 89 and 81 % as compared to that of the monoculture models, respectively. The effective nitrogen and phosphorus contents of rhizospheric soil of intercrops sugarcane and soybean were increased by 66 and 311.7 %, respectively, as compared to those in the monoculture system. Microbe number of rhizosphere soil in the intercropping pattern increased significantly as compared to those in the monoculture models. The quantities of bacteria, fungi, and actinomyces increased by 42.62, 14.5 and 78.5 % in the intercropping sugarcane, while the intercropping soybean increased by 188, 183 and 73 %, respectively. Therefore, growing sugarcanes in combination with soybean can be considered a good agriculture management practice, helping to promote plant growth, yield and increase soil nutrients.

Keywords Sugarcane · Soybean · Intercropping · Soil microbe · Soil enzyme activity

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Introduction

Sugarcane is a major crop in tropical and subtropical regions of the South China, occupying about 1.4 million hectares. In general, sugarcane has a juvenile period of 100–110 days, so that the intercrops of soybean and sugarcane are widely practiced. Sugarcane is generally planted in 80–100 cm rows, and soybean could be intercropped between two rows of sugarcane at the same time. Recently, the wide-rowed sugarcane plantations with the preferred space of 120–140 cm are tested, which are conducive to conduct intercropping and benefit both crops in intercropping system (Huang 2002). Intercropping has been recognized as a potential system for the augments of productivity over space and time in subsistence farming situations. There is generally a trend toward high yield under intercropping. Even in areas where yield of the companion crop was substantially reduced, total yield was greater (Evan 1960; Aggarwal et al. 1992). Imam et al. (1990) and Bokhtiar et al. (1995) reported that sugarcane intercropping with potato helped to increase both the yields of potato and cane.

The sugarcane crop depletes a considerable amount of nutrients from soil, but soybean in intercropping pattern increases productivity per unit of land and enables the crops more effectively utilize nutrients and improve soil fertility and field ecological conditions (He et al. 2006; Tang et al. 2005). An intercropping partly meets the N requirement of the companion crop due to the transfer of the symbiotically fixed N from the legume to the non-legume (Ledgard et al. 1985). Nitrogen, phosphorus and potassium utilization efficiency in maize/mungbean intercropping was significantly higher than that of the monoculture system (Chowdhury and Rosario 1994), and the organic matter content of sugarcane soil increased due to companion cropping of pulses (Yadav et al. 1987).

Intercropping usually benefits from increased microbial number, and hence improved soil enzyme activity (Chai et al. 2005). Microorganisms abound in the soil are critical to decomposing organic residues and recycling soil nutrients. Soil enzymes involved intimately in the cycling of nutrients, effect fertilizer use efficiency, reflect the microbiological activity in soil and act as indicators of soil change (Dick 1994; Ruggiero and Bollag 1996; Gianfreda and Bollag 1996). Li et al. (2000) studied that the quantity of microbes was positively correlated with the urease activity in wheat/soybean intercropping.

In the present study, our objective was to investigate the growth, yield, rhizosphere soil microbes and enzyme activity related to nutrient availability under sugarcane and soybean intercropping conditions.

Materials and methods

Plant materials

The sugarcane variety ROC22 (*Saccharum officinarum*) and soybean HuaChun5 (*Glycine max* L.) were used as the plant materials for the experiments.

Treatments

The treatments include: intercropped sugarcane and soybean, monoculture sugarcane, and monoculture soybean. Each treatment was replicated three times. A plastic potted method was used (150 cm length, 50 cm in width, 50 cm in depth) (Fig. 1).

Plants were grown in a greenhouse under natural light and temperature conditions. The experiment was carried out three times from June 2010 to August 2012. In this paper, the most recent results are shown. Every growing pot contained 30 kg dry (soil belongs to red soil type with pH 5.0, 65.60 mg/kg N, 10.06 mg/kg P), sieved soil and two sugarcane plants or three soybean plants were planted under the monoculture system, or two sugarcane plants, with three soybean plants under the intercropping culture system (Fig. 1). All the treatments were designed in three replications. Pots were rotated periodically. Plants were supplied only tap water until foliage leaves were emerged and then supplied Arnon–Hoagland solution for every 7 days. Plants were harvested periodically until the soybean flowering period and measured the fresh weight and length. Then they were dried in a ventilated oven at 65 °C for 5 days and measured the dry weight. The data obtained were statistically analyzed by student's t test (Stat View 5.0, SAS Institute Inc.) and SPSS 13.0 software.

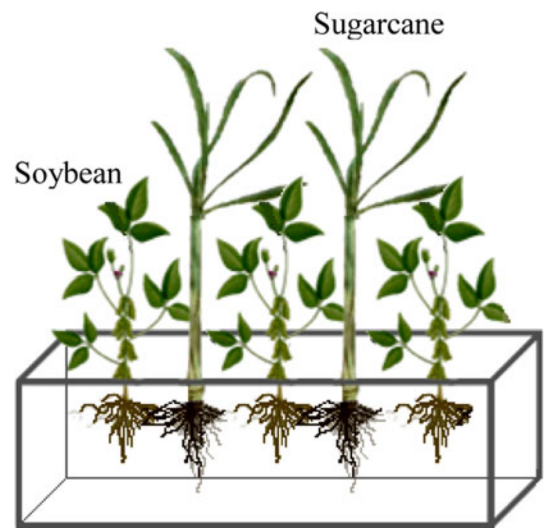

Fig. 1 Illustration of the culture container of the sugarcane/soybean intercropping

Sampling: plants along with soil were taken out from the pots, the adhered soil near the roots was stripped gently, maintained in sterilized paper bags for analysis.

Soil analysis

The number of bacteria, fungi and actinomyces in rhizosphere soil was investigated with a diluting flat method and counting technique. The media used for these counts comprised (1) tryptone yeast extract for bacteria; (2) caseinate-asparagine agar for fungi; and (3) potato dextrose agar for actinomycetes. The analysis of urease and acid phosphatase measurements was carried out by the method of Hoffman, Johnson and Hoffman, respectively (Guan 1986). Inorganic nitrogen in soil was measured by the semi-micro Kjeldahl procedure; inorganic phosphate and potassium in soil were by flame photometry; organic matter was carried out by the potassium dichromate oxidation method of Walkley and Black (Liu et al. 1996).

Measurement of nitrogen-fixing activity

Nitrogen-fixing activity of nodulated roots was measured by the acetylene reduction method of Sasakawa (Sasakawa et al. 1986).

Results

Plant dry matter weight and yield

Sugarcane showed the increasing effect in intercropping sugarcane and soybean, but soybean showed a certain degree of plant dry matter loss during intercropping. Results showed that dry weight of biomass and yield under sugarcane/soybean intercropping was increased by 35.44 and 30.57 % for sugarcane, and decreased by 16.12 and 9.53 % (100-grain weight) for soybean, respectively (Fig. 2; Table 1). The total biomass and yield were increased by 21.5 and 10.37 % than monoculture models, respectively (Fig. 2; Table 1). Thus, mixed grown sugarcane and soybean have some degree of advantages in terms of growth and yield.

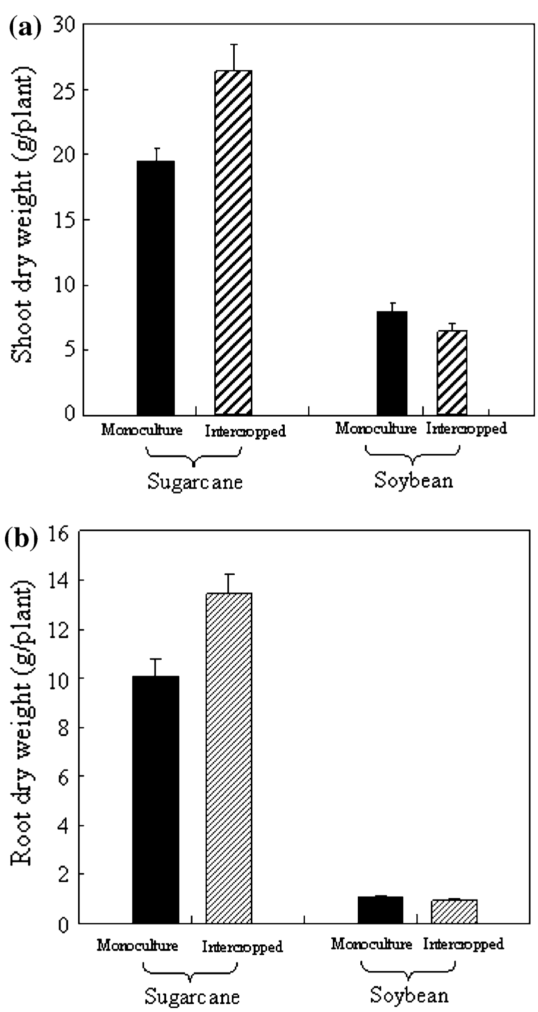

Fig. 2 Dry weight of **a** shoots and **b** roots of two crops in the sugarcane/soybean intercropping

Table 1 Effects of sugarcane/soybean intercropping on yield of mature period

Culture mode	Sugarcane (g/plant)		Soybean
	Fresh weight	Dry weight	100-grain weight (g)
Monoculture	50.75 ± 5.34	17.99 ± 1.51	18.25 ± 1.44
Intercropping	61.40 ± 3.06*	23.49 ± 1.42*	16.51 ± 0.87

* Indicated significant difference at 0.05 level

Rhizosphere soil nitrogen, phosphorus and potassium

Intercropping improved the soil inorganic nitrogen and phosphorus in the intercropping sugarcane and soybean. The inorganic nitrogen content of soybean rhizospheric soil in the intercropping system was 217.02 mg/kg, approximately 66 % higher than those in the monoculture system (Fig. 3). A slight increase in the inorganic nitrogen of intercropping sugarcane was also observed. Inorganic phosphorus content in intercropping sugarcane and soybean was 93.52 and 123.58 mg/kg, approximately 199 and 311.7 % higher than those in the sole plantation, respectively (Fig. 4). Potassium and organic matter contents were also increased slightly in the intercropping system, respectively (Figs. 5, 6).

Soil microorganisms

Photographs of the microbial culture are shown in Figs. 7, 8, and 9. The microbial decomposition of the crop residues

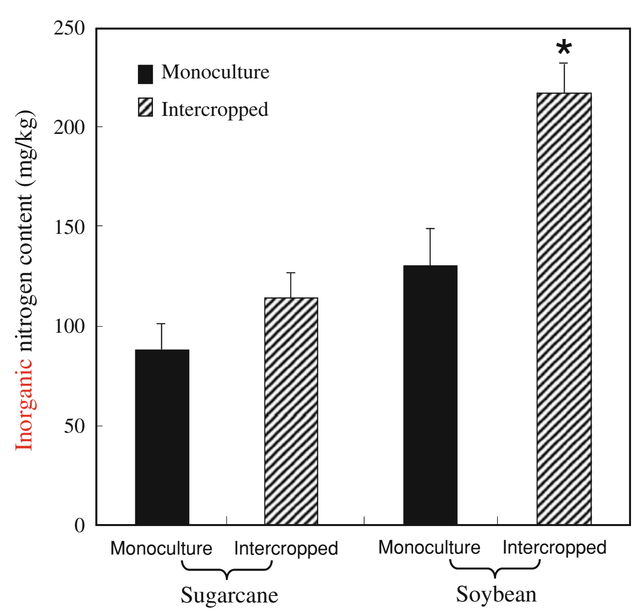

Fig. 3 Inorganic nitrogen contents of two crops in the sugarcane/soybean intercropping. *Asterisk* indicate significant difference against monoculture at the 5 % level Student's *t* test

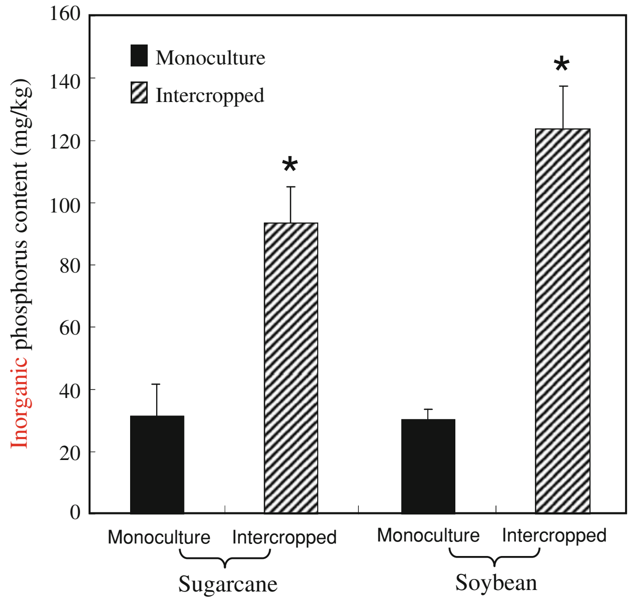

Fig. 4 Inorganic phosphorus contents of two crops in the sugarcane/soybean intercropping. *Asterisk* indicate significant difference against monoculture at the 5 % level Student's *t* test

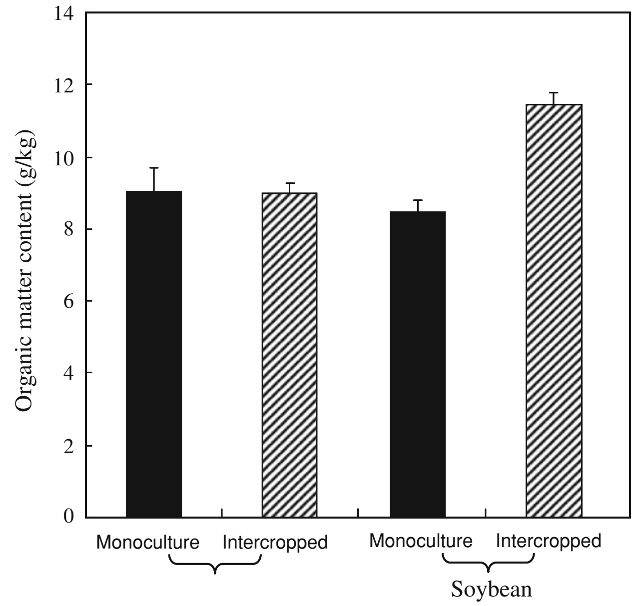

Fig. 6 Organic matter contents of two crops in the sugarcane/soybean intercropping

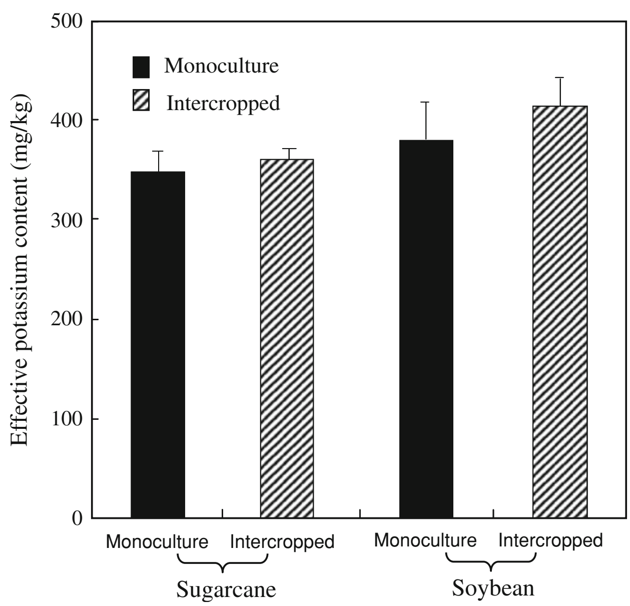

Fig. 5 Effective potassium contents of two crops in the sugarcane/soybean intercropping

could provide nutrients to the plant. Soil microbe numbers varied greatly under different treatments in this study (Table 2). Total soil microbe (bacteria, fungi and actinomyces) number was significantly higher in sugarcane-soybean combinations as compared with both monoculture plantations. The increase of bacteria, fungi, and actinomyces in the intercropping soybean was occurred more remarkably than in the monoculture sugarcane. The quantities of bacteria, fungi, and actinomyces in the intercropping sugarcane were 5.8×10^6, 3.62×10^4 and 6.39×10^5, increased by 42.62, 14.5 and 78.5 %, respectively, while in the intercropping soybean were 9.13×10^6, 3.1×10^4 and 6.78×10^5, increased by 188, 183 and 73 % as compared to that of the monoculture soybean, respectively (Table 2).

Enzyme activities of rhizosphere soil

The acetylene reduction activities (ARAs) of the intercropping models were 0.71 μmol $C_2H_4^{-1}$ $plant^{-1}$ higher than those in the monoculture soybean (1.02 μmol $C_2H_4^{-1}$ $plant^{-1}$) (Fig. 10). The urease in both intercropping models of sugarcane (0.7421 mg/g) and soybean (0.8076 mg/g) were significantly promoted by 89 and 81 % as compared to that of the monoculture models, respectively (Table 3). Intercropping models also showed slightly greater acid phosphatase activity than monoculture models, but not significantly (Table 3).

The correlation of microorganisms quantity and enzyme activity

The results showed that the bacteria quantity in the soil, ranked first, accounts for 91.5 % of total microorganisms during the whole growing period of the seedlings, and then were actinomyces and fungi (Table 2). Further, analysis showed that the total quantity of bacteria, fungi and actinomycete in the intercropping was positively correlated

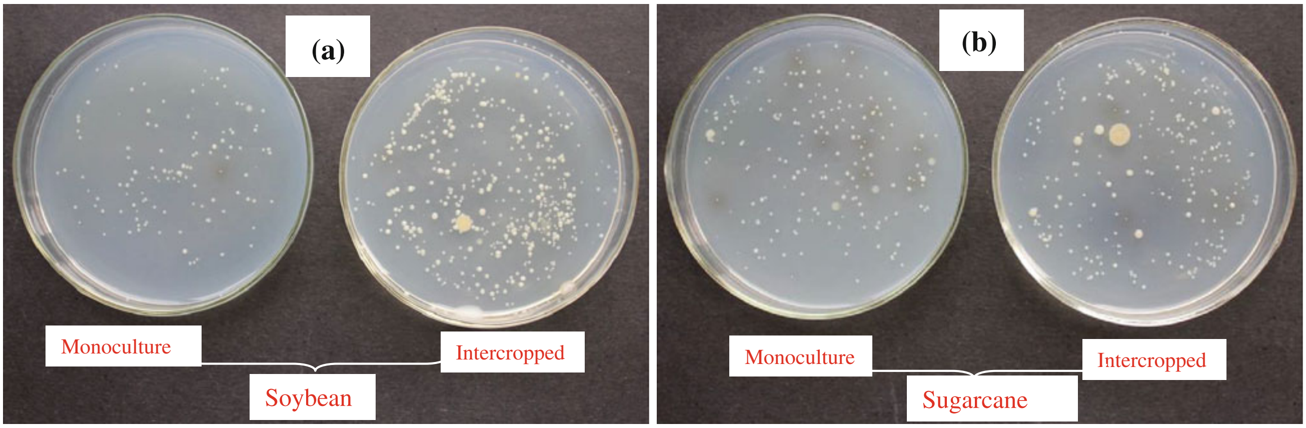

Fig. 7 Bacteria quantity of two crops in the sugarcane/soybean intercropping. **a** Indicates soybean, **b** indicates sugarcane

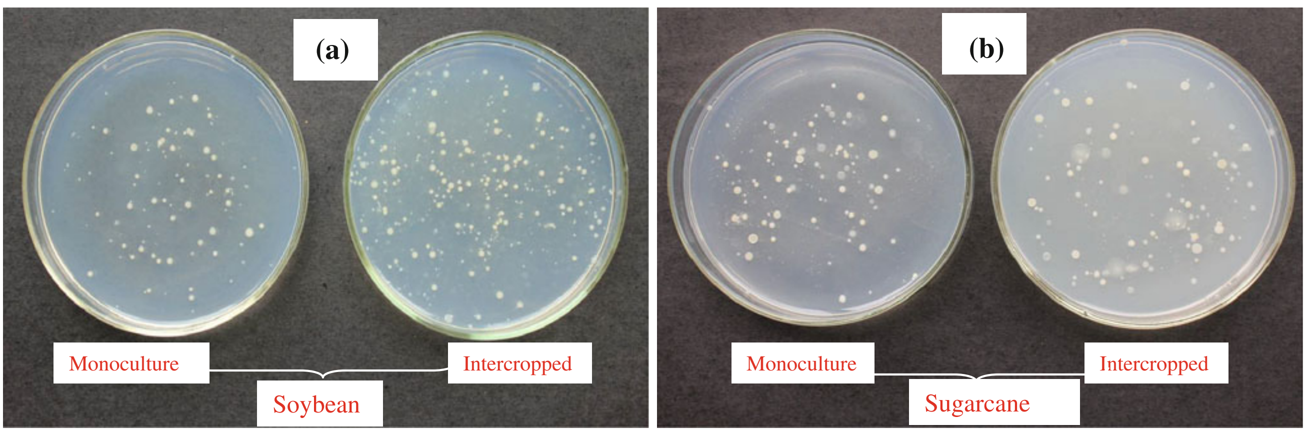

Fig. 8 Fungi quantity of two crops in the sugarcane/soybean intercropping. **a** Indicates soybean, **b** indicates sugarcane

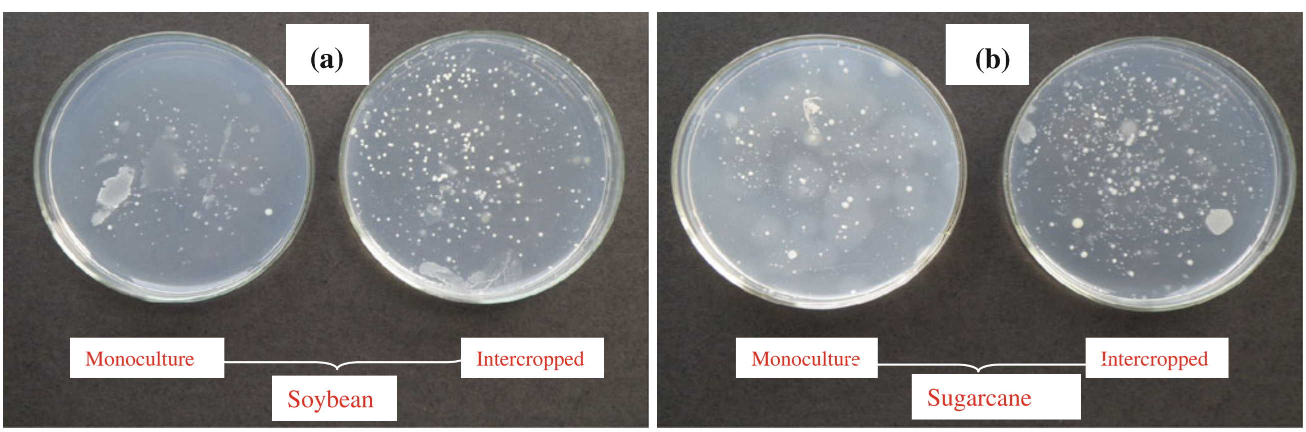

Fig. 9 Actinomyces quantity of two crops in the sugarcane/soybean intercropping. **a** Indicates soybean, **b** indicates sugarcane

with enzyme activity. The correlation coefficient of bacteria, fungi and actinomycete was 0.8843, 0.5289, 0.958 with urease, and 0.5843, 0.8780, 0.8665 with phosphatase, respectively (Table 4).

Discussion

Previous reports showed that intercropping of cereal and legumes has many advantages in terms of growth and some

Table 2 Microbe quantity of two crops in the sugarcane/soybean intercropping

Determination index (strains/g dry soil)	Sugarcane		Soybean	
	Monoculture	Intercropped	Monoculture	Intercropped
Bacteria (10^6 strains/g dry soil)	4.06	5.80*	3.17	9.13**
Fungi (10^4 strains/g dry soil)	3.16	3.62*	1.8	3.1*
Actinomyces (10^5 strains/g dry soil)	4.53	6.39*	3.91	6.78*

* Significant difference against monoculture at the 5 % level Student's *t* test

** Significant difference against monoculture at the 1 % level Student's *t* test

other agronomical properties (Singh et al. 1986; Putnam et al. 1986). There are also significant handicaps of mixed grown component crops such as root competition for water and nutrients and competition for light (Ofori and Stern 1987). Sathyavely et al. (1991) studied on intercropping sugarcane with pluses and oilseeds, all of which were not significantly different for cane grown either in mixtures or in pure stands. However, our study indicated that the biomass and yield of intercropped sugarcane were significantly higher than that in the monoculture sugarcane, suggesting sugarcane-soybean combinations can promote the growth and yield of sugarcane (Fig. 2; Table 1). By contrast, the biomass and yield of soybean in sugarcane-soybean combinations were lower than that of the monoculture soybean (Fig. 2; Table 1). This reduction may reasonably be attributed to competition for nutrients or water, or a combined effect of these factors. The total biomass and yield of sugarcane-soybean combinations were higher than those of the monoculture system (Fig. 2; Table 1). These suggested that mixed grown sugarcane and soybean have some degree of advantages in terms of growth. The ARAs of the intercropping soybean was significantly higher than those in the monoculture (Fig. 10). This may be due to the higher demand for nitrogen in sugarcane, as soybean itself fixes nitrogen and has a lower demand for nitrogen, and sugarcane roots absorbed more nitrogen, thus stimulating the soybean biological nitrogen fixation.

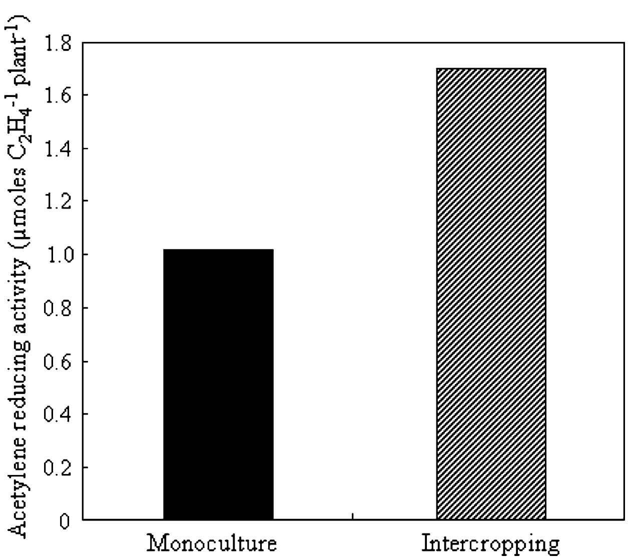

Fig. 10 Acetylene reducing activity of soybean nodulation in the sugarcane/soybean intercropping

In this study, soil microbe numbers varied greatly under both intercropping and monoculture treatments (Table 2). Compared with sole plantation of sugarcane or soybean, the numbers of bacteria, fungi and actinomyces were increased significantly. The differences in soil microorganisms might be attributed to a combined factor, such as root biomass, root exudates, root and microclimatic environment of community. The microbial decomposition of the crop residues could provide nutrients to the plant, thus a positive relationship between the abundance of microorganism and nutrient and soil organic matter, which has been confirmed by some studies (Berg et al. 1998; Marschner et al. 2002).

The urease activities in the intercropping system were significantly higher than those in the monoculture system (Table 3). The quantity of microbes was positively correlated with urease and phosphatase activities (Table 4), these results were in accordance with Li et al. (2000). Enzyme activities in soil are important to support those biochemical processes which are essential for the maintenance of soil quality (Moscatelli et al. 2001). Our data showed the inorganic nitrogen in the intercropping system was significantly higher than that of the monoculture system (Fig. 3). This is in agreement with a previous report of

Table 3 Enzyme activities of two crops in the sugarcane/soybean intercropping

Determination index	Sugarcane		Soybean	
	Monoculture	Intercropped	Monoculture	Intercropped
Urease (mg NH_3-N/100 g soil 24 h)	39.13	74.21*	44.65	80.76*
Acid phosphatase (mg P_2O_5/g soil 24 h)	1.69	1.83	1.63	1.75

* Significant difference against monoculture at the 5 % level Student's *t* test

Table 4 The correlation coefficient of the total microbe quantity and enzyme activity in the intercropping

Enzyme activity	Soil microbe		
	Bacteria	Fungi	Actinomycess
Urease	0.8843*	0.5289*	0.958*
Acid phosphatase	0.5843*	0.8780*	0.8665*

* Positively correlation at the 5 % level by SPSS software analysis ($n = 18$)

Singh et al. (1986). In addition, the phosphorus content had also a significant increase and a slight increase in potassium and organic matter content was also obtained in our experiment. These may be due to the more soil microbes that are present, the more unavailable nitrogen can be more converted into inorganic nitrogen compounds which will be absorbed by plants, accelerating nitrogen transformation, and improving nitrogen utilization. Unavailable nitrogen can be more converted into inorganic nitrogen as the urease activities increase.

In conclusion, intercropped sugarcane with legumes are far more effective than monoculture sugarcane to produce higher shoot dry weight, increase the quantity of microorganism which was positively correlated with enzyme activity, involve in organic matter decomposition and nutrient cycling in intercropping system.

Author contribution XP Li and H Nian conceived and designed the study; XP Li, YH Mu, YB Cheng and XG Liu performed the experiments; XP Li analyzed data and wrote the paper; H Nian revised the paper. All authors read and approved the final manuscript.

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