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RESEARCH ARTICLE

Effects of Intercropping with Peanut and Silicon Application on Sugarcane Growth, Yield and Quality

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Abstract Field experiments were conducted in two consecutive years (2013 and 2014) in order to explore the effects of intercropping sugarcane with peanut and silicon (Si) application on cane growth, yield and quality, and soil nutrients on acidic soil. The plant height was significantly increased with Si and intercropping + Si. The stalk diameter and stalk fresh weight were significantly enhanced with intercropping, Si application and intercropping + Si, except with intercropping in 2013. The yield, brix, pol, sucrose, and purity were remarkably increased, but reducing sugar and fiber content were significantly decreased with intercropping, Si application and intercropping + Si. Soil organic carbon (SOC), soil phosphorus (P), soil potassium (K), and soil Si content were enhanced with intercropping, Si application and intercropping + Si. Thus, by using intercropping with peanut and Si application, the plant growth, yield and quality of sugarcane and soil nutrient could be improved.

Keywords Intercropping · Silicon · Sugarcane · Yield · Quality

Introduction

Sugarcane (*Saccharum* spp.) is an important industrial crop, belonging to the family Poaceae and Andropogoneae tribe, which is distributed widely in all tropical and subtropical regions of the world (Li et al. 2018a, b). Sugarcane is also mainly grown in China, especially in Guangxi, Guangdong, Yunnan, and Fujian provinces. However, acidic soils cover most of the land and soil acidification has accelerated in these provinces in last decades (Guo et al. 2010). In recent years, sugarcane plantlets grown on acidic soils in southern China have suffered from severe chlorosis (Huang et al. 2016), leading to reduced sugarcane yield and juice quality at maturity.

Silicon (Si) is the second most abundant element in the earth's crust and enhances plant tolerance to several biotic and abiotic stresses (Ma 2004; Liang et al. 2005; Li et al. 2017; Bakhat et al. 2018; Li et al. 2018a, b). Sugarcane, as Si-accumulating plants, absorbs more Si than any other mineral element, accumulating approximately 380 kg ha^{-1} Si in a 12-month-old crop (Savant et al. 1999; Borges et al. 2016). Bokhtiar et al. (2012) also reported that compared to unamended control, Si-amended treatments significantly increased cane yield by 66% and 15% in two different soils. However, Si deficiency occurs commonly in most soils of southern China.

Intercropping is a farming practice involving two or more crops growing together and coexisting on the same site for a time (Brooker et al. 2008). The increased yield with intercropping is due to improved resource use efficiency of water, nutrients, land, solar radiation, and atmospheric CO_2 (Li et al. 2009; Isaac et al. 2012), as well as ameliorated soil acidification (Li and Rengel 2012). In recent decades, the number of studies has increased substantially on sugarcane under intercropping system with different crops due to the benefits of intercropping on soil nutrient, sugarcane growth and yields (Gana and Busari 2003; Li et al. 2013; Luo et al. 2016; Solanki et al. 2017).

Peanut (*Arachis hypogaea* L.) is an important legume providing edible proteins and N_2 fixation, which are usually utilized as cover crop, intercropped with cereals and

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other staple foods. Previous studies (Li et al. 2013; Luo et al. 2016) showed that productivity advantages of intercropping may arise from complement use of growth resources such as N on acid soil in southern China, but few researches on peanut/sugarcane intercropping concerned on the sugarcane quality in acid soil. So, the objective of this study was to investigate the effect of intercropping and Si addition on the growth, yield and quality of sugarcane and soil nutrient on acid soils in southern China.

Materials and Methods

Experimental Design

The experiment was conducted in 2013 and 2014 at Zengcheng Experimental Station (23°14’N, 113°38’E) of South China Agricultural University, Guangzhou City, Guangdong Province, China, where it has tropical ocean monsoon climate with long time summer and abundant rainfall. The annual average temperature is 21.9 °C, and annual rainfall and evaporation are 1696 and 1591 mm, respectively. The soil type is classified as latosolic red soil. Five soil samples were collected from different parts of the experimental field and bulked into a composite sample and used for the determination of the chemical and physical properties of the soil before planting. The values of soil pH and organic carbon (C) were 5.67 and 14.51 g kg^{-1} soil, and soil total nitrogen (N), available phosphorus (P) and available potassium (K) averaged 1.07, 0.13 and 0.22 g kg^{-1} soil, respectively.

In March 2013 and 2014, sugarcane cultivar (*Saccharum officinarum* L. Panyu chewing cane) was planted in a plot with 5 m long and 3 m apart. Two rows of peanut cultivar (*Arachis hypogaea* L. Yueyou 7) were sown between 1 m of conventional row spacing of sugarcane (Fig. 1). Two silicon does (0 and 60 kg ha^{-1}, the source of silicon: Ca-Mg silicate) was applied in the furrow before planting sugarcane. All of the treatments were adjusted to receive the same quantities of calcium (Ca) and magnesium (Mg) by applying lime and/or magnesium chloride ($MgCl_2$) as necessary. There were four replications of the cultivars arranged in a randomized complete block design.

Fertilizers were soil-applied prior to planting at rates of 40 kg ha^{-1} of N, 100 kg ha^{-1} of P_2O_5 and 100 kg ha^{-1} of K_2O (10-25-25). Before grand growth phase, surface fertilization with N (100 kg ha^{-1} of N; ammonium sulfate) and K (60 kg ha^{-1} of K_2O; KCl) was performed, according to de Camargo et al. (2014). All plots received common cultural practices including tillage and herbicide application. Peanuts were harvested on July 18, 2013, and July 24, 2014. Sugarcanes were harvested on December 31, 2013, and December 30, 2014.

Soil Sampling

Soil samples were collected before crops planting (in February), after peanut harvesting (in July) and after sugarcane harvesting (in December) corresponding to approximately 0, 5, and 10 months after planting, respectively. Ten soil (0–15 cm) cores (Φ = 2.54 cm) were randomly collected within each of the 36 field plots and composited. The samples were placed in polythene papers, transported to the laboratory for analysis. In the laboratory, the soil samples were dried, ground and sieved through a 1-mm sieve prior to analysis.

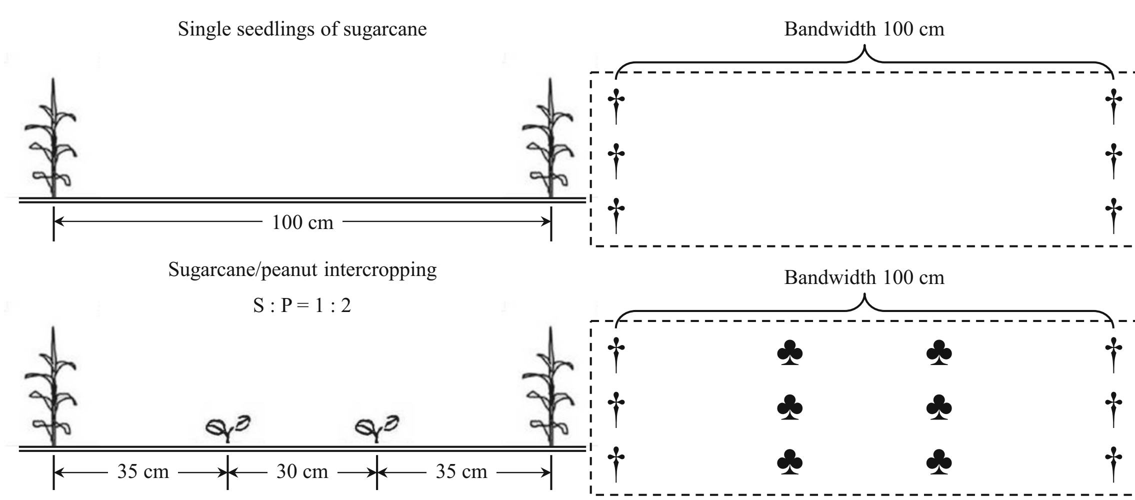

Fig. 1 Illustration of the culture container of the sugarcane/peanut intercropping

Soil Nutrients Analyses

Soil organic carbon (SOC) content was measured with the wet digestion method (Walkley and Black 1934). Phosphorus (P or P_2O_5) was measured colorimetrically at 882 nm using the molybdenum blue method (Allen et al. 1976). Soil exchangeable potassium (K) was extracted using the ammonium acetate method (Richards and Bates 1989) and determined by using an atomic absorption spectrophotometry (AAS). Determination of soil Si was based on measurement of absorbance at 790 nm of heteropoly molybdenum blue formed by reduction with ascorbic acid at room temperature (Raben-Lange et al. 1994).

Sugar Yield and Quality Analyses

At harvest, plant height, stalk diameter, stalk fresh weight, cane yield, and quality parameters were determined. Stalk fresh weights were determined by cutting and weighing 20 stalks from 2 of the middle 4 rows of each plot (40 stalks total) in December 2013 and 2014. The weight of each harvested plot was used to calculate cane yield (10^4 kg cane ha^{-1}). A random sample of billets (about 10 kg) was collected from each plot during harvest. The billets were chipped and shredded using a pre-breaker, and juice was expressed from a 1-kg subsample of the chipped stalks by pressing at 21 MPa for 2 min. The remaining fiber cake was weighed, dried at 66 °C for 72 h in a forced-air oven and reweighed to determine the fiber content (Lingle et al. 2010). Ten stalks from each plot were milled and the crushed juice analyzed for pol (%), brix (%), purity (%) and reducing sugar (%) at harvest. Pol (%) refers to the percentage of sucrose content in juice, and purity (%) refers to the ratio of sucrose content to the total soluble solids in juice. Pol (%), brix (%) and purity (%) were determined with a Sucrolyser (combination of sucromat, digital automatic saccharimeter and ABBEMAT-HP automatic refractometer) according to the method of Tewari and Irudayaraj (2003). Reducing sugar (%) was determined following the Marques et al. (2016) methods.

Statistical Analysis

All data collected were analyzed using SPSS (version 20.0, IBM corp., USA). Two-way analysis of variance (ANOVA) was used to test for significant differences among intercropping, Si application and their interactions using a Tukey's post hoc analysis with an alpha value of 0.05. Graphs were plotted using GraphPad Prism (version 5.0.1, GraphPad Software Inc., San Diego, CA).

Results and Discussion

Average Monthly Precipitations and Temperature

The monthly average temperatures and precipitation for both years along with monthly 5-year average are shown (Figs. 2, 3). Meanwhile, the average monthly temperatures for both 2013 and 2014 were fairly uniform, and fairly similar to 5-year averages, but the average amount monthly precipitation of 2 years was substantially different from the 5-year average and almost 0 mm at January and October. In 2013, compared with the average, the precipitation was much higher which occurred from March until September as well as during harvesting in December. This high rainfall could potentially lead to higher accumulation of biomass. In 2014, the higher-than-average precipitation occurred from March until August, but the precipitation was much lower than average from September to October (nearly 0 mm). Muchow et al. (1996) reported that the time trend in stalk sucrose accumulated with maximum sucrose yield occured 100 days before final harvest. These confirmed the results that drought limits the uptake of nutrition and reduces the dry matter accumulation of sugarcane (Lingle et al. 2010).

Effect of Intercropping and Si on Sugarcane Yield

The effect of intercropping and Si application on sugarcane yield varied as shown in Table 1. In terms of ANOVA result for plant height, stalk diameter, stalk fresh weight and yield of sugarcane, significant changes were observed on pattern (sugarcane monoculture and sugarcane–peanut intercropping) and Si in 2013, and between pattern, Si and interaction in 2014, except the interaction of plant height. Compared to sugarcane monoculture, the plant height, stalk diameter, stalk fresh weight and yield were significantly enhanced by Si application and intercropping + Si

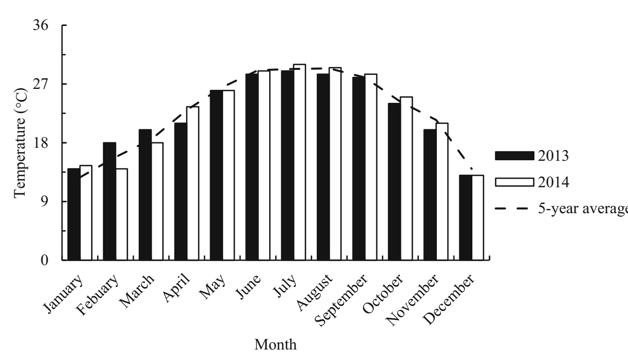

Fig. 2 Average monthly temperatures along with 5-year average in Zengcheng Experimental Station Guangzhou City, Guangdong Province, from the beginning of season until harvest for 2013 and 2014

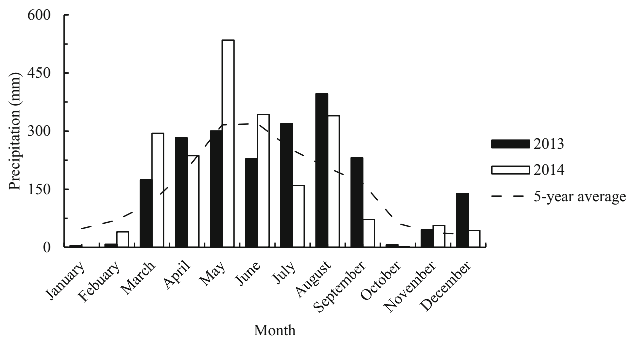

Fig. 3 Average monthly precipitation along with 5-year average in Zengcheng Experimental Station Guangzhou City, Guangdong Province, from the beginning of season until harvest for 2013 and 2014

treatments in 2 years, and significantly increased by intercropping only in 2014 (except for plant height). The yield was much higher with Si treatment in 2013 than monoculture, which was related to reduce lodging by Si application (Savant et al. 1999). It has been shown that Si is known to increase yields of sugarcane growing in low Si (Savant et al. 1999). The yields of cane and sugar have been increased by 10–50% on soils low in Si in Hawaii (Ayres 1966). It has also been reported that Si could improve sugarcane growth (Meyer and Keeping 2000) and increase yield in field-grown sugarcane (Samuels 1969; Preez 1970; Ross et al. 1974; Borges et al. 2016).

The previous studies have reported that the intercropping with leguminous crops can achieve an enhanced biomass and yield compared with monoculture (Zhang et al. 2011). Intercropping with peanut was more consistently positive effect on sugarcane growing on latosolic red soil in two consecutive years. This result is consistent with previous findings (Li et al. 2007) in which intercropping increase maize yield with faba bean in the field.

Effect of Intercropping and Si on Sugarcane Quality

Experiment had a significant effect on sugarcane quality (Fig. 4). Compared with monoculture, the content of brix, pol, sucrose and purity were significantly increased, but the content of reducing sugar with intercropping, Si application and intercropping + Si. The same trend was apparent on brix and sucrose from seven generations of sugarcane (Lingle et al. 2010). Zarekar et al. (2017) have reported that intercropping sugarcane with groundout could improve brix, pol and purity, but not influenced to the significant extent. The content of fiber was also significantly decreased with intercropping + Si. This result is consistent with Ashraf et al. (2009) findings in which the brix and pol in

Table 1 Effects of intercropping with peanut and silicon application on plant height, stalk diameter, stalk fresh weight, and yield of sugarcane at harvest stage in 2013 and 2014

Treatment	Plant height (cm)	Stalk diameter (cm)	Stalk fresh weight (kg plant^{-1})	Yield (10^4 kg ha^{-1})
2013				
Monoculture	279.66 ± 7.43 c	26.18 ± 0.89 b	1.63 ± 0.08 b	8.60 ± 0.11 d
Intercropping	286.23 ± 7.60 bc	26.95 ± 0.71 ab	1.69 ± 0.09 ab	8.89 ± 0.11 c
Monoculture + Si	292.67 ± 8.27 ab	27.50 ± 0.71 a	1.73 ± 0.07 a	9.19 ± 0.11 b
Intercropping + Si	296.33 ± 8.11 a	28.00 ± 0.62 a	1.77 ± 0.09 a	9.33 ± 0.13 a
Source of variation	*F* values from ANOVA			
Pattern	4.237*	7.328*	3.325NS	34.432***
Si	21.624***	25.831***	11.688**	197.093***
Pattern × Si	0.343NS	0.322NS	0.208NS	4.007NS
2014				
Monoculture	269.84 ± 8.61 c	25.28 ± 0.54 b	1.54 ± 0.05 b	8.34 ± 0.11 c
Intercropping	280.29 ± 9.81 bc	26.27 ± 0.67 a	1.65 ± 0.07 a	8.62 ± 0.11 b
Monoculture + Si	289.90 ± 8.70 ab	27.05 ± 0.75 a	1.69 ± 0.08 a	8.91 ± 0.10 a
Intercropping + Si	293.16 ± 9.38 a	26.98 ± 0.63 a	1.68 ± 0.06 a	9.01 ± 0.10 a
Source of variation	*F* values from ANOVA			
Pattern	5.624*	4.943*	4.192*	30.073***
Si	32.443***	35.921***	17.339***	189.350***
Pattern × Si	1.547NS	6.562*	8.536**	6.559*

The values represent the mean ± standard deviation of ten replications per treatment. Different letters indicate significant differences between the treatment means within the same column and year according to the Tukey's post hoc analysis. N.S., not significant; *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$ level of significance according to a Tukey's post hoc analysis

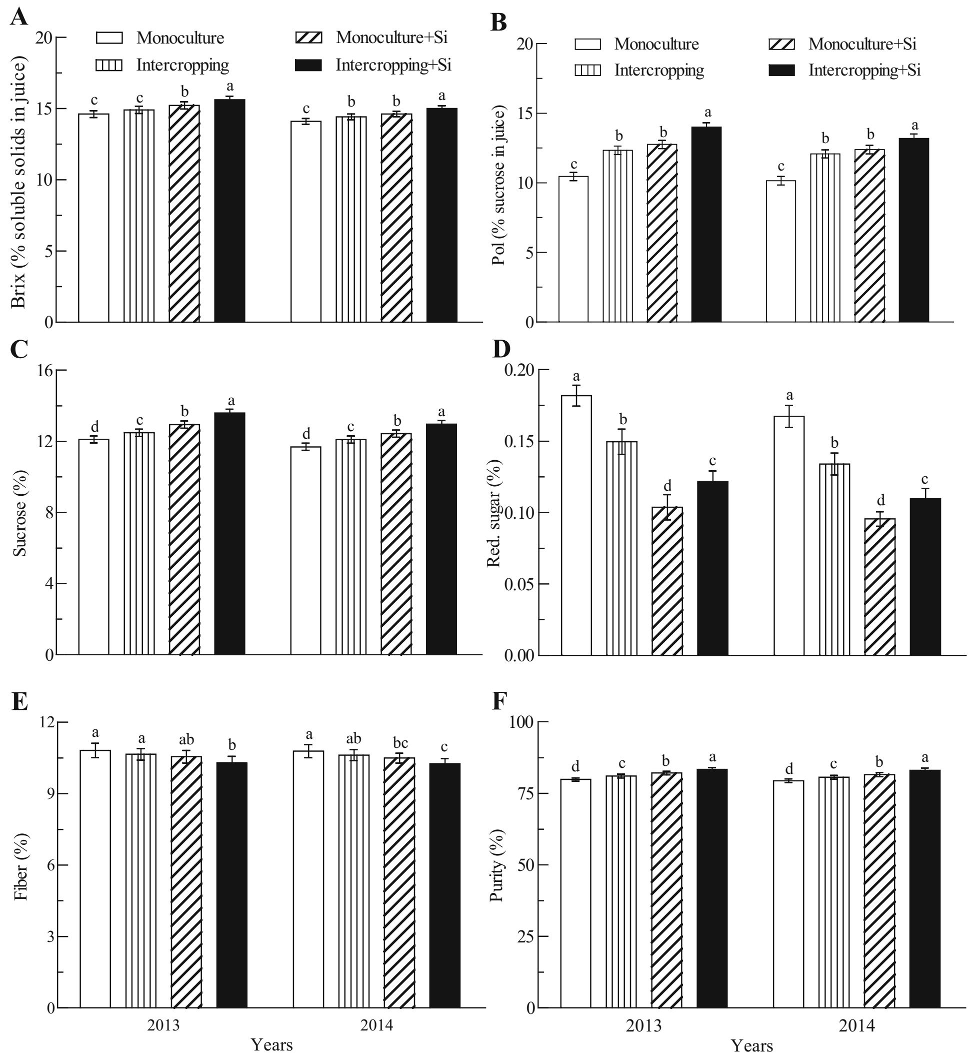

Fig. 4 Effects of intercropping with peanut and silicon application on brix (% of soluble solids) (**a**), pol (**b**), sucrose content (**c**), reducing sugar (**d**), fiber content (**e**) and purity (**f**) of sugarcane at harvest stage. The values represent the mean ± S.D. of ten replications per treatment. Different letters indicate significant differences ($p < 0.05$) according to a Tukey's post hoc analysis

juice of sugarcane were significantly improved with the supplementation of Si under salt stress.

Effect of Intercropping and Si on Soil Nutrient

Soil organic carbon (SOC), P, and K were significantly positively correlated with intercropping in the sugarcane harvest time (Fig. 5). Compared with monoculture, the content of SOC was increased with Si application, intercropping and intercropping + Si in 2013 and 2014. Cong et al. (2015) have reported that intercropping increases SOC decomposition by using soil samples from a 7-year field experiment with maize, wheat and faba bean. A similar trend was observed for P and K in soil. However, the content of Si was increased with Si applied soil, as Si deficiency occurs commonly in these soils.

Conclusions

The improved SOC and P of soil nutrients enhanced the yield and brix and sucrose of sugarcane by using intercropping with peanut and Si application. The highest sucrose content observed was much lower than that achieved in more tropical environments.

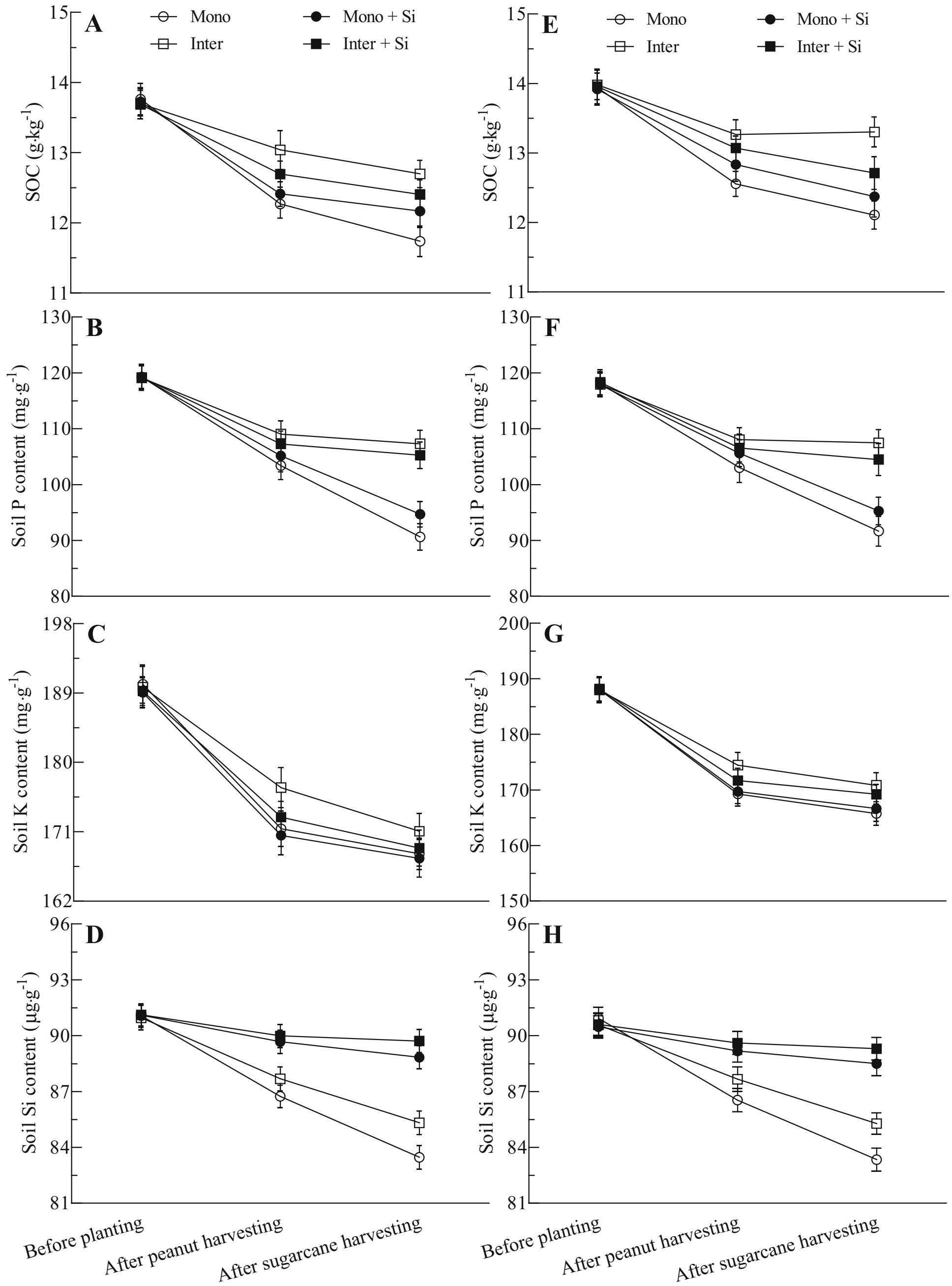

Fig. 5 Effects of intercropping with peanut and Si application on soil organic carbon (SOC) (**a**, **e**), P (**b**, **f**), K (**c**, **g**), and Si (**d**, **h**) in 2013 (**a**, **b**, **c** and **d**) and 2014 (**e**, **f**, **g** and **h**). The values represent the mean ± S.D. of ten replications per treatment

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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