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Responses of soybean lodging and lodging-related traits to potassium under shading by maize in relay strip intercropping system

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The relay strip intercropping system of maize-soybean is dominant in southwest China. Compared to monoculture, the productivity of soybean is unstable in this system, since soybean seedling grow under shading by maize, which beget elongated plants and prone to lodging. Therefore, a 3-year study was conducted to determine the influence of K on lodging and lodging-related traits of soybean, and to identify the key traits associated with lodging resistance in relay strip intercropping system in Sichuan Province, China during 2008-2010. The results showed that K application significantly affected basal stem diameter, stem breaking strength, total nonstructural carbohydrate (TNC) concentration, concentration of K and lignin, while differences in plant height and weight of basal internode were not significantly. The K-fertilized treatments had higher seed yield and seed ratio than treatment without K application. The lodging had significantly negative correlation with grain yield, seed ratio, basal stem diameter, weight of basal internode, stem breaking strength, concentration of lignin and K, but no correlation was observed between lodging and TNC in both pot and field trial. The plant height was positively correlated with lodging only in field trial. Thus, these results suggested that K application could alter the lodging-related traits in soybean for greater lodging resistance, and it may be worthwhile to focus on basal stem diameter, stem breaking strength, and lignin concentration.

Key words: Lodging, potassium, relay strip intercropping, soybean, stem characteristic.

INTRODUCTION

Multi-cropping system, the agricultural practice of cultivating two or more crops in the same space during a single growing season, is an old and commonly used cropping practice which aims to maximum the productivity of system to meet the food demand for the increasing population. The main advantage is the more efficient utilization of the available resources and the increased productivity compare with each sole crop of the mixture (Willey, 1979; Carubba et al., 2008; Launay et al., 2009). However, there existed intense interspecific competition in growth resources such as light, water, and nutrients for planting several crops in the same space (Lithourgidis et al., 2011). In that case, the short height crop grows in shading by taller crops in this system. It means interspecific interaction decreases light interception amount of the short height crop during the co-existence stage of two or more crop species (Zhang and Li, 2003), which leads to weaker plant and susceptible

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to lodging. According to Akunda (2001) and Ephrath et al. (1993), in multi-cropping system, shading, can cause severe lodging in short height crops because of the absence of effective light interception which could serve as smaller main-stem diameters and elongated lower internodes. In a lodged plant community, the normal canopy structure of soybean is destroyed, resulting in reduced photosynthetic ability and dry matter production (Hitaka, 1969; Setter et al., 1997). Therefore, it is vital for increasing the lodging resistance in short height crop to maximum the productivity of multi-cropping system through agronomic measurement.

The relay strip intercropping of maize-soybean, which is one type of multiple cropping systems and can increase total yield per land area compared to monocultures of the same crops. This relay strip intercropping system has been practiced traditionally in a large scale in southwest of China (Yan et al., 2010). The system is one of the important agricultural systems to meet the local food needs and to ensure food security in China. However, the soybean seedling grown in the condition of shading by maize, the earlier-planted and taller maize form relatively higher canopy structures than soybean and the roots of maize grow to a greater depth than those of soybean in this system (Holmes and Smith, 1977). Thus, the maize intercepts more sunlight than soybean. So, the soybean yields are suppressed, mainly due to the soybean suffered adverse competition in environment resources such as water, nutrients and radiation (Willey, 1990) from maize, which leaded to growth affected considerably, easier to lodging.

Lodging can reduce plant growth severely frequently, although researchers found that the agronomic management can alleviate lodging incidence, especially on potassium (K) supply, which is one of major nutrients considered essential for crop growth and yield development (William, 2008). Mondal and Miah (1985) and Sindhan and Parashar (1986) reported that the K-fertilized plants were resistant to lodging, insufficient tissue K is known to increase lodging incidence. K application increase in synthesis of carbohydrates in the plant tissues consequently making plants resistant to lodging, increased 1000-seed weight and decreased seed infection (Sharma and Kolte, 1994).

In Iraq, N nutrition and K availability are key factors in isolating the cause of lodging in rice production systems, increased and timely N supply without K application, promoting vigorous vegetative growth and increased panicle size and weight, may result in lodging (Bhiah et al., 2010). K significantly increased plant height (<30%) and stem diameter (30 to 80%) in all rice varieties, although the differences between varieties were observed. According to Ookawa and Ishihara (1992) and Bhiah et al. (2010), lodging occurred primarily from the base, due to poor root growth in the absence of K. They recognized that plant height was not necessarily the most important factor in determining lodging resistance. The susceptibility to lodging differs among cultivars with similar plant heights. Among morphological traits, stem diameter and weight have been directly correlated with lodging resistance and the breaking strength of the stem (Zuber et al., 1999). As in wheat, have shown that the K fertilization can help lessen stalk lodging, and the yield improvement with K fertilization generally comes about because of increases in the kernel weight, which agrees with the report of Sharma et al. (2005) and Sweeney et al. (2000).

Resistance of soybean to lodging is important for seed yield, especially when grown under shading condition. This is because legumes are sensitive to shading and they were grown under shading by corn in relay strip intercropping system of maize-soybean, resulting in thinner stems and elongated plant (Yan et al., 2010; Lithourgidis et al., 2011). These results were similar to those of Duncan et al. (1990), who reported that relay intercropped plants developed more slender stems and had thinner main-stem diameters, as compared with singlecropped. Lodging resistance in soybean has been associated with breaking strength, plant height, stem diameter and weight (Liu et al., 2007; Zhou et al., 2007). Stalk chemical constituents such as lignin, total nonstructural carbohydrates (TNC), K and nitrogen (N) have been used to estimate lodging in maize and soybean (Xiang et al., 2010; Zuber et al., 1957; Hondroyianni et al., 2000). Based on these results, it can be concluded that no single morphological trait and chemical constituent can be of practical use in selection for lodging resistance (Esechie et al., 2004). But, the knowledge about the importance of morphology and mechanical characteristics of soybean in relay strip intercropping system is very scarce, more information is needed on relationship between lodging and stem characteristic.

Most of the soybean crop in southwest of China is grown in the condition of shading by maize in vegetative period. In this system, as a note of caution, however, the soybean is tending to be ignored in fertilization application as its N fixation in conventional practice. In recent years, although several studies have evaluated the effect of fertilizer application on growth and yield of soybean under multiple cropping systems, the detailed study on effects of K on lodging and lodging-related traits of soybean is highly scarce in relay strip intercropping system. So, the objective of this study was to investigate the effect of K on lodging, agronomic traits, mechanical characteristics and biochemical composition of soybean in relay strip intercropping system, and to identify the key traits associated with lodging resistance.

MATERIALS AND METHODS

Experimental site and cultivar

The studies include a field trial at the experimental site of Shehong

Table 1. Potassium fertilizer dosage (g/pot for pot trial, g/plot for field trial) for different levels.

Treatment	K fertilizer dosage at different levels[a]					
Field trial	K0	K1	K2	K3		
	0.0(0.0)[b]	33.9(67.8)	67.8(135.6)	101.7(203.4)		
Pot trial	K0	K1	K2	K3	K4	K5
	0.00(0.00)	0.92(1.84)	1.84(3.68)	2.76(5.52)	3.68(7.36)	4.60(9.20)

[a] Fertilizers were applied on 22 June 2008 for field trial, but on 3 June in 2009 and 13 June in 2010 for pot trial. [b] Data outside the parenthesis were the amount of K_2O and that in the parenthesis were the amount of sulfate potassium.

county (30°52'N, 105°23'E, 510 m above sea-level with annual rainfall of 950 mm) in 2008 and two out-door pot trials at the Experimental Farm of Sichuan Agricultural University (29°54'N, 103°01'E, 620 m above sea-level with annual rainfall of 1719 mm) in 2009 and 2010. The Gongxuan 1 cultivar for soybean and Chuandan 418 for maize were provided by Zigong Institute of Agricultural Science and Maize Institute of Sichuan Agricultural University, respectively. The soil of field experiment was clay-loam in texture and acid in reaction (pH 6.52) with available N, P, K, total N, P, K and organic matter being 151.44, 38.85 and 51.24 mg/kg, 1.82, 14.96, 12.04 and 12.04 g/kg respectively. The soil of pot experiment was a brown loamy sand in texture and acid in reaction (pH 6.55) with organic matter, total N, P, K, available P, K and alkaline N being 8.96, 1.21, 0.61 and 11.44 g/kg, 25.34, 65.70 and 62.35 mg/kg, respectively.

Experimental design and fertilizer application

In this study, four K levels in field trial and six K levels in pot trial were applied, forming treatments for the trials (Table 1). 17 kg/ha of phosphorus (P_2O_5) and 60 kg/ha of N were also applied as preplanting fertilization. In the pot trial, the same soil, fertilizer and pots were used during 2009 and 2010. The fertilizers used were urea (46.3% N), calcium superphosphate (12% P_2O_5), and sulfate potassium (50% K_2O).

Pot trial

In the pot trial, 2 m wide strips were prepared. On these strips, the maize for 2 rows with 2 plants per drill was sown on 1 m wide area of the strips on 29 March 2009 and 5 April 2010, respectively. The other strip (1 m wide) for pot, and the distance was 44.0 cm between maize and pot. The maize was harvested on 5 August 2009 and 13 August 2010, respectively.

Plastic pots (33.5 cm in diameter, 31 cm in height) were each drilled five holes (1 cm in diameter) in the bottom for leaching. Each pot contained 19 kg of air dried soil. There were six treatments (labeled K0, K1, K2, K3, K4, and K5). Six pots for each treatment, only three plants in each pot with three replicates. All of N, P and K were mixed and blended evenly with the top 15 cm soil before sowing. Soybean pots were placed in two rows in every strip between the strips of maize (Figure 1A and Table 2). Six seeds were sown in each pot on 3 June in 2009 and 13 June in 2010, respectively, and seedlings were thinned to three at the early vegetative VC stage (cotyledons) (Figure 1B).

Field trial

In order to gain the condition of shading by maize (Table 2), the 1.13 m wide strips were prepared. The maize was sown on 0.2 m wide area of the strips on 2 April 2008. On the strip of maize, 1 row for maize was planted with 2 plants per drill, the other strip (0.93 m wide) for soybean, and the distance was 33.3 cm between bordering maize and soybean rows. The four treatments (Labeled K0, K1, K2 and K3 as shown in Table 1) were randomly arranged with three replicates on 9.04 m^2 (1.13 × 8 m) area of plots with 2 rows. Fertilizers were drilled at the time of 15 days after germination. Five or six soybean seeds were sown for each drill on 3 June 2008 with row spacing of 46.5 cm. Seedling were thinned to three at the VC stage with a density of 1.01×10^5 plants/ha. The rest of the management was based on the higher standard of field production.

Data collection

Stem characteristics

Nine and fifteen successive plants for the pot trial and the field trial, respectively, were sampled and measured at V5 stage. Plant measurements taken were basal stem diameter, plant height, weight of basal internode. The basal stem diameter was measured with a vernier caliper. Stem breaking strength was estimated as previously described in sorghum (Esechie and Maranville, 1975). Basal stem sections was determined after oven drying at 65°C to constant weight and then weighed. They were then ground in a sample mill to through a 1 mm screen and used for chemical analysis. TNC determination followed the procedures described by Smith (1969). The method described by Goering and van Soest (1970) was used for lignin determination, while K was determined by the dry ashing method reported by Isaac and Kerber (1971).

Lodging

Lodging plants were those in which the stems were completely or partially broken or leaned 30°or more from the vertical. The severity of lodging was assessed at R5 (The beginning seed stage). The lodging was calculated in the following formula:

$$\text{Lodging (\%)} = \frac{\text{The number of Lodged Plant in each treatment}}{\text{The number of all plants in each treatment}} \times 100$$

Seed yield and seed ratio

The soybean was harvested at R8 stage (the full ripe stage) for seed yield. The pod was separated into seed and pod shell, which were oven-dried at 65°C for 48 h to weigh. Seed ratio was calculated as dry weight of seeds/dry weight of pod×100.

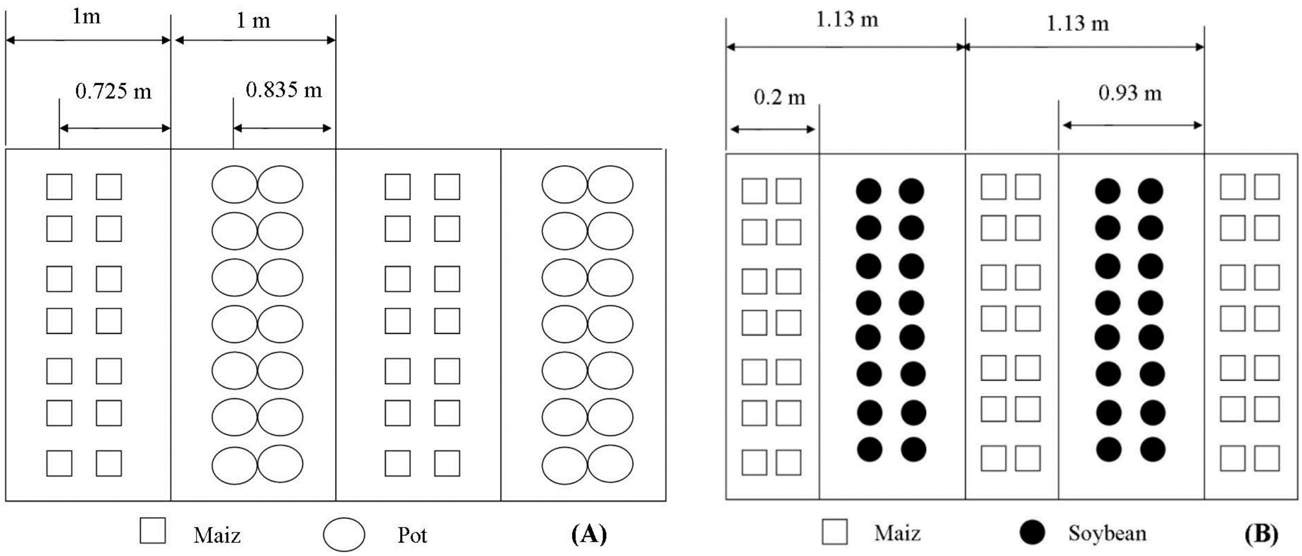

Figure 1. (A) Out-door pot experiment; (B) Field experiment. In the outdoor experiment 2 m wide strips were prepared; 1 m for maize with 2 rows and 2 plants per hole were sown in the end of March, the soybean for 3 plants per pot in the beginning of June. The distance was 44.0 cm between maize and pot. The 2 rows of plastic pots were placed between maize strips for obtaining shading condition, and the soybean was planted in the pot with an equilateral triangle way; In the field experiment, in order to gain the condition of shading by maize (Table 2), the 1.13 m wide strips were prepared. The maize was sown on 0.2 m wide area of the strips on 2 April 2008. On the strip of maize, 1 row for maize was planted with 2 plants per drill, the other strip (0.93 m wide) for soybean, and the distance was 33.3 cm between bordering maize and soybean rows. Five or six soybean seeds were sown for each drill on 3 June 2008 with row spacing of 46.5 cm. Seedling were thinned to three at the VC stage.

Table 2. The climatological data of the soybean strips in experimental sites.

Experiment		Temperature (°C)		Relative humidity (%)		Photosynthetically active radiation (μmol/m^2/s)	
		Shading by maize	Non-shading	Shading by maize	Non-shading	Shading by maize	Non-shading
Field 2008		24.5	26.8	79	73	27	325
Pot	2009	25.9	27.3	74	69	42	289
	2010	25.4	28.1	70	68	41	278

The data were collected at the V3 stage for soybean in sunny day. The relative humidity and temperature were measured with dry-wet thermograph (TDWS-A2) in the middle position of soybean at 11:00 am. The chlorophyll fluorescence spectrometer (MINI-PAM) was used to investigate the photosynthetically active radiation (PAR) of canopy in soybean.

Statistical analysis

Microsoft Excel 2003 and Microsoft Office Publisher were adopted for data processing and drawing of figures. These data were subjected to analysis of variance, and means were compared using Duncan's multiple range test (P < 0.05). Regression analysis was also performed to determine the relationships between variables. All calculations were performed by SPSS Statistics 17.0.

RESULTS

Seed yield and seed ratio

The average seed yield of the treatment without K was 2389.41 kg/ha, compared to the 2681.55 kg/ha for K-fertilized treatment in field trial. Seed ratio of the treatment with K application (62.86) in field trial was higher than that of the treatment without K (56.30). In the pot trial (Table 3), the highest average seed yield across years reached 16.92 g/plant. Among the treatments, the K3 had the highest seed yield, differing significantly from K0, K1, and K5. The seed yield increased from K0 to K3 significantly as the K rate increased from 0 to 2.76 g/pot, and then declined from K3 to K5 as the K rate dropped form 2.76 to 4.6 g/pot. No significantly difference of trend in seed yield between years was observed. For the field trial, the seed yield was increased with the increment of K application. Consequently, K3 had a significant higher

Table 3. Comparison of means combined over years for characteristics of soybean under shading by maize (2008–2010).

Characteristics	Field trial				Pot trial			
	K0	K treatment	Group F value	Entry (K) F value	K0	K treatment	Group F value	Entry (K) F value
Lodging (%)	49.53	40.44	36.98*	11.35*	59.81	36.60	67.69*	19.17**
Seed yield (kg/ha; g/plant)	2389.41	2681.55	1255.41**	116.13**	9.58	14.20	260.90**	7.58**
Seed ratio (%)	56.30	62.86	84.21*	75.58**	61.64	65.80	30.48*	17.59**
Plant height (cm)	83.89	81.11	1.26^{NS}	0.32 ^{NS}	66.75	62.44	6.24 ^{NS}	3.40 ^{NS}
Basal stem diameter (cm)	0.42	0.54	33.23*	4.23^{NS}	0.33	0.39	50.04*	0.63 ^{NS}
Weight of basal internode (g)	0.37	0.40	3.90 ^{NS}	0.31 ^{NS}	0.40	0.53	9.38 ^{NS}	0.74 ^{NS}
Stem breaking strength (kg)	0.14	0.17	196.94**	17.77*	0.18	0.34	71.12*	78.87**
TNC (mg/kg)	12.00	14.82	35.72*	1.12 ^{NS}	12.47	16.41	49.49*	24.28**
K (mg/kg)	1.79	2.08	125.49**	41.02**	1.06	1.66	231.60**	18.68**
Lignin (%)	18.16	20.87	324.96**	10.83*	16.72	18.06	428.52**	5.72*

*, ** Significant at the 5 and 1% probability levels, respectively; NS, not significant; TNC, total nonstructural carbohydrates. The units of kg/ha and g/plant were use for field trial and pot trial, respectively. The group F value showed difference between K-fertilized treatment and K0 treatment. The entry (K) F value showed difference among K-fertilized treatments.

seed yield (2832 kg/ha) than any others, which was high enough at the present field production.

The highest average seed ratio (69.05%) across years was obtained with application of K3 in pot trial. As the K application significantly increased from K0 to K3, the seed ratio was increased. However, after the point, no significantly difference as the K rate increased. The K-fertilized plants developed significant greater seed ratio in field trial (Table 3). The seed ratio was significantly higher for K3, followed by the K2, K1, and K0. Although difference existed among treatments, these followed a similar trend in pot and field trial.

Lodging

Average lodging severity was 49.53 and 59.81% in the field trial and pot trial without K application compared to the 40.44 and 36.60% under the condition of K application, respectively. The results of both pot and field experiments suggested that the K-fertilized plants developed significantly lower lodging than plants from K0 treatments, and the lodging was also significantly difference among the K-fertilized treatments (Table 3). In the pot trial, the lodged plants from the K3 treatment was significantly fewer than those plants from K0, K1, and K3 treatment but similar those plants from K4 and K5 treatments (Table 4). A similar trend in lodging was observed in two years (2009 and 2010). For the field trial, the increase in K application was associated with decrease in the severity of lodging. A significant lower lodging was found in plants from K3 treatment (Table 4).

Stem morphological characteristics

From combined analysis over the years (Tables 3 and 4), it was observed that the K-fertilized plants produced a thicker basal stem diameter and stiffer stem than plants from K0 treatment. The K application increased the basal stem diameter and stem breaking strength. The K3 treatment had the thickest stem diameter among the treatments, which was significantly thicker than those plants from K0 and K1. The stem breaking strength was increased with the increasing dose of K application. K application groups had the thicker stem and larger stem breaking strength than K0 group. The difference was significantly in K-fertilized plants, but the K1 and K2 treatment was similar. The plant height was decreased with the increment of K dose from K0 to K3, which increased as the K rate increased to K5, but all the difference was not significantly. The weight of basal internode followed a similar with plant height when the K fertilizer was applied, and no significantly difference among the treatments was observed.

Stem chemical characteristic

The stem chemical characteristics of soybean under shading by maize responded significantly to K in relay strip intercropping system (Tables 3 and

Table 4. Soybean yield, lodging and stem characteristics under different levels of K application.

Treatment		Plant height (cm)	Basal stem diameter(cm)	Weight of basal internode (g)	Stem breaking strength (kg)	Lignin (%)	TNC (mg/kg)	K (mg/kg)	Lodging (%)	Seed ratio (%)	Seed yield (kg/ha)
Field trial 2008	K0	83.9^{a}	0.42^{c}	0.37^{a}	0.14^{c}	18.2^{c}	12.0^{b}	1.8^{c}	49.5^{a}	56.3^{d}	2389.4^{d}
	K1	82.3^{a}	0.49^{bc}	0.38^{a}	0.16^{b}	19.8^{b}	14.8^{a}	2.0^{b}	44.1^{b}	59.2^{c}	2489.7^{c}
	K2	81.1^{a}	0.55^{ab}	0.39^{a}	0.17^{b}	21.1^{a}	15.1^{a}	2.0^{b}	41.4^{b}	63.2^{b}	2723.0^{b}
	K3	79.9^{a}	0.58^{a}	0.42^{a}	0.18^{a}	21.7^{a}	14.6^{a}	2.2^{a}	35.9^{c}	66.2^{a}	2832.0^{a}

Treatment		Plant height (cm)	Basal stem ^{d}iameter(cm)	Weight of basal interno^{d}e (g)	Stem ^{b}reaking strength (kg)	Lignin (%)	TNC (mg/kg)	K (mg/kg)	Lo^{d}ging (%)	See^{d} ratio (%)	See^{d} yiel^{d} (g/plant)
Pot trial 2009	K0	66.0^{a}	0.27^{c}	0.36^{b}	0.16e	16.9^{d}	12.3^{c}	1.04^{d}	62.2^{a}	61.9^{d}	7.79^{c}
	K1	62.7^{a}	0.30^{b}	0.48^{ab}	0.23^{d}	18.0^{bc}	15.1^{b}	1.35^{c}	51.1^{b}	63.7^{d}	9.04^{c}
	K2	58.7^{a}	0.30^{ab}	0.53^{ab}	0.25^{d}	17.9^{c}	17.9^{a}	1.60^{b}	40.0^{c}	64.3^{cd}	12.12^{ab}
	K3	58.0^{a}	0.32^{a}	0.63^{a}	0.35^{c}	19.1^{a}	18.7^{a}	1.72^{a}	28.9^{d}	69.1^{a}	13.14^{a}
	K4	58.0^{a}	0.31^{ab}	0.48^{ab}	0.43^{b}	18.6^{ab}	15.4^{b}	1.73^{ab}	33.3^{cd}	66.8^{ab}	10.66^{abc}
	K5	66.0^{a}	0.29^{b}	0.49^{ab}	0.49^{a}	18.1^{bc}	13.9^{bc}	1.93^{a}	31.1^{d}	66.5^{bc}	10.18^{bc}
Pot trial 2010	K0	67.5^{a}	0.39^{c}	0.44^{a}	0.20^{d}	16.5^{c}	12.6^{d}	1.08^{d}	57.4^{a}	61.4^{d}	11.36^{c}
	K1	65.4^{a}	0.42^{bc}	0.44^{a}	0.23^{d}	17.5^{b}	15.4^{c}	1.36^{c}	48.2^{b}	62.4^{cd}	15.57^{b}
	K2	64.2^{a}	0.46^{ab}	0.54^{a}	0.29^{c}	17.6^{b}	17.4^{ab}	1.61^{b}	38.9^{c}	64.0^{c}	15.94^{b}
	K3	62.1^{a}	0.51^{a}	0.63^{a}	0.34^{b}	18.9^{a}	18.0^{a}	1.70^{b}	29.6^{d}	69.0^{a}	20.69^{a}
	K4	63.9^{a}	0.46^{ab}	0.53^{a}	0.41^{a}	17.3^{bc}	16.4^{bc}	1.73^{b}	33.3^{cd}	65.9^{b}	17.33^{b}
	K5	65.4^{a}	0.50^{a}	0.48^{a}	0.41^{a}	17.4^{bc}	16.2^{bc}	1.90^{a}	31.5^{d}	66.2^{b}	17.34^{b}

Means within a column of the same year followed by a different letter are significantly different ($P < 0.05$) according to the Duncan multiple range test; TNC, total nonstructural carbohydrates.

4). The K-fertilized plants from K3 treatment attained significantly higher lignin and TNC (total nonstructural carbohydrates) than plants from K0, K1, and K5 treatment in pot trial, but similar to those plants from K2 and K4 treatments. For the field trial, K3 and K2 treatment had higher lignin and TNC, respectively. K application could alter the TNC content, although there were no significant differences among K-fertilizer treatments. The increase in K application was significantly related with increase in lignin content of soybean, but the difference between K2 and K3 treatments were not significant. K-fertilized plants produced a significantly higher K content in plant tissue than plants from K0 treatment, the K content of plant tissue increased with the increment of K application. Both pot and field trials showed a similar trend during 2008 and 2010.

Relationship between lodging and stem characteristics

Lodging was negatively correlated with seed yield ($R = -0.96^{*}$) in the field trial (Table 5) as well as in pot trial ($R = -0.91^{**}$) (Table 6). Seed ratio was negatively correlated with lodging in the field trial, and the parameters showed a same trend in the pot trial ($R = -0.93^{**}$). The K application had no effect on the plant height of soybean, and the K group differences were not also observed (Table 3). While the lodging were positively correlated ($R = 0.99^{**}$) with plant height in field trial, there was no correlation between plant height and lodging in the pot trial. On the other hand, significantly negatively correlation existed between lodging and weight of basal internode in field and pot trial. The basal stem diameter and stem breaking strength were negatively correlated

Table 5. Correlation of matrix of lodging, seed yield, seed ratio, and stem characteristics of soybean in field trial (2008).

Parameter	Lodging	Seed yield	Seed ratio	Plant height	Basal stem diameter	Weight of basal internode
Seed yield	-0.96*					
Seed ratio	-0.98**	1.00**				
Plant height	0.99**	-0.98**	-0.99**			
Basal stem diameter	-0.97**	0.98**	0.98**	-0.99**		
Weight of basal internode	-0.97**	0.97**	0.98**	-0.96*	0.93*	
Stem breaking strength	-0.98**	0.96*	0.97**	-0.99**	0.99**	0.92*

*, ** Significant at the 5 and 1% probability levels, respectively.

Table 6. Correlation of matrix of lodging, seed yield, seed ratio, and stem characteristics of soybean in pot trial (2009-2010).

Parameter	Lodging	Seed yield	Seed ratio	Plant height	Basal stem diameter	Weight of basal internode
Seed yield	-0.91**					
Seed ratio	-0.93**	0.93**				
Plant height	0.65^{NS}	-0.82*	-0.66^{NS}			
Basal stem diameter	-0.97**	0.94**	0.93**	-0.61^{NS}		
Weight of basal internode	-0.76*	0.95**	0.87*	-0.84*	0.82*	
Stem breaking strength	-0.89**	0.63^{NS}	0.78**	-0.32^{NS}	0.79*	0.41^{NS}

*, ** Significant at the 5 and 1% probability levels, respectively; NS, not significant.

Table 7. Correlation matrix of lodging and chemical constituents of stem of soybean in field and pot trial (2008-2010).

Parameter	Field trial			Pot trial		
	Lodging	Lignin	K	Lodging	Lignin	K
Lignin	-0.97**			-0.81*		
K	-0.99**	0.97**		-0.96**	0.66^{NS}	
TNC	-0.73^{NS}	0.82^{NS}	0.80^{NS}	-0.75^{NS}	0.87*	0.62^{NS}

*, ** Significant at the 5 and 1% probability levels, respectively; NS, not significant; TNC, total nonstructural carbohydrates.

with lodging in field trial, but the stem breaking strength was not correlated with lodging in the pot trial. Similarly, lodging was negatively correlated with lignin (R＝ -0.97**) and K (R＝-0.99**) in field trial (Table 7), and followed a similar trend in the pot trial. TNC had no relationship with lodging but was correlated with lignin in pot trial. Similarly, Lignin was positively correlated with K.

DISCUSSION

Crops with high percentages of lodging generally had lower yield, hence the highly significant negative correlation between lodging and yield (Tables 5 and 6). Similar results were reported by Kang et al. (1999) and Kheiralla et al. (1993) for the correlation between lodging and yield in spring wheat and maize. Cooper (1971) observed that lodging was a major factor contribution to a yield decrease in highly productive environments. According to the production practice the lodging can decrease soybean yields by up to 10%. It was have reported that agronomic measurement such as K fertilizer application could reduce lodging and to increased seed yield (Sharma and Kolte, 1994). In this study, the K significantly reduced the lodging by 9.09 and 23.21% in field and pot trial, respectively. On the other hand, the yield of soybean has increased by 12.23% in field trial and 48.23% in pot trial from the K-fertilized treatment, compared to the K0 treatment (Table 3). These results also fully confirmed the improvement of lodgingresistance was the key of increased yield of soybean in relay strip intercropping.

Esechie et al. (2004) reported that the shelling percentage is probably the most underrated component of yield in maize and there is a paucity of information about the relationship of this yield component to lodging. According to this study, lodging was negatively correlated with seed ratio which was an indication that relay strip intercropping soybean with low seed ratio was more tend to lodging. The K-fertilized plants with higher seed ratio were more resistant to lodging than the plants without K application with a relatively lower seed ratio. Active remobilization of stem assimilates to the developing pod may be the case in those plants prone to lodging. In effect, even though remobilization may enhance shelling percentage, it depletes the stem of those assimilates, thereby making it more susceptible to lodging (Esechie et al., 2004). In maize, the similar results were also observed that exhaustive translocation of carbohydrates from the lower stem to the developing ear resulted in parenchyma disintegration which aggravated lodging, especially in the event of K deficiency (Liebhardt et al., 1968). However, in this study, if we assume that the stronger stem result from the more assimilates in stem, the less assimilates transferring to pod will account for the lower seed ratio, and then our results were opposite. Therefore, further study on seed ratio is needed to be developed for its role in lodging in relay strip intercropping soybean.

According to Wilcox and Sediyama (1981), the soybean has shown a positive correlation between lodging and plant height. Similar results were also obtained by Tripathi et al. (2004) who reported the plant height of spring wheat was significantly positive correlated with lodging. In this study, lodging was correlated with plant height in field trial, but there was not significantly in pot trial. This is consistent with the results of Islam et al. (1992), who reported that plant height was not necessarily the most important factor in determining lodging resistance. Even so, it was obvious that the short height of plant, the less lodging incidence in this study. The K-fertilized plants had the lower plant height than those plants form K0 treatment in relay strip intercropping system, but the differences were not significantly (Table 3). Our results are inconsistent with those of Kadam and Wadje (2011) and William (2008) who reported the K application can obtain higher plant height. Therefore, this suggested that the more information is needed on the relationship among plant height, K and lodging in soybean under shading by maize.

The K application significantly increased the basal stem diameter of soybean in this system. The basal stem diameter was significantly negatively correlated with lodging which was an indication that the severity of lodging in soybean could be reduced by increasing the basal stem diameter. In soybean, the importance of stem diameter to lodging resistance has been reported (Ball et al., 2005; Freitas et al., 2002; Zhou et al., 2010). Our results are similar to Thompson (1964) who reported that a 0.02 mm decrease in rind thickness accounted for a 1.56% increase in lodging in maize. Simultaneously, Foley (1962) observed that the higher internodes are not as strong as the lower ones; the stalk was most highly correlated with total stalk breakage in the field (Schertz et al., 1978). Therefore, in our study, the K-fertilized plants with thicker basal stem diameter were responsible for lower lodging, compared with the plants from K0 treatment. The K application was the important factor in increasing basal stem diameter and decreasing lodging.

The high stem breaking strength is often attributed to its low lodging (Mobasser et al., 2009). In our study, the lodging was highly and negatively correlated with stem breaking strength (Tables 5 and 6). K-fertilized plants developed a significantly greater stem breaking strength than other plants form K0 during 2008 and 2010 (Tables 3 and 4). Obviously, a more sturdy plant that is, a plant with a weighty section when plants fertilized with moderate K. In effect, the results of both pot and field trial showed that the weight of basal internode was negatively correlated with lodging; the plants without K application displayed more lodged than K-fertilized plants. This appears to suggest that weight of basal internode may have a significantly effect on lodging consideration. Therefore, we concluded that the weight and diameter of basal stem are strongly affected by K application. In this way, we can take the cultural practices such as K application to increase the diameter and weight of basal stem for enhancing the lodging resistance of soybean in relay strip intercropping system.

The K concentration of the stem in soybean was associated with lodging. Although the K is known to influence the various physiological and biochemical processes in plants, the role of K in plants is complex. In previous reported, the K concentration of the stem was positively correlated with stem breaking strength (Liebhardt et al., 1968). The similar results were obtained in our study. However, the K is well known to have not a direct relation to stem breaking strength but its catalytic role especially in carbohydrate metabolism. Our results suggest that the K has no bearing to lodging in soybean because K was not significant correlated with TNC. The K application should be account for the increasing of K concentration in K-fertilized plants.

Present studies have also further suggested that there is a higher concentration of TNC in plants stem of soybean with K application than those plants from K0 treatment (Table 4). However, the lodging in relay strip intercropping soybean was not associated with TNC (Table 7). Our results are not in agreement with those of Esechie et al. (2004), and Albrecht et al. (1986) who reported lodging resistance in maize was associated with concentrations of TNC in the stalk. In effect, Hondroyianni et al. (2000) observed that no relationship between lodging and stalk sugar concentrations in maize. The carbohydrate content may only be an indirect indication of the healthiness and vigor of a plant rather having a direct relation to lodging. The K fertilizer application enhanced the carbohydrate metabolism of soybean, and finally increased the concentrations of TNC. Similar results are in confirmation with reports by Maranville (1974).

Differences in lignin concentration of stem among treatments with different K levels were significant and relatively consistent across years (Tables 3 and 4). The K concentration on moderate level of K fertilization (K3) was significantly higher than other treatments. The results showed that plants with more lignin concentration are less susceptible to lodging, and the lignin was significantly and negatively correlated with lodging. However, Undersander et al. (1977) found the distribution of lignin in the rind is important for lodging resistance rather than lignin content. Therefore, we suggested that the lignin concentration may not be considered in isolation but in combined with TNC concentration. In this study, the K-fertilized plants developed higher lignin and TNC concentrations, which were less lodging than those plants from K0 treatment. The plants applied moderate level of K fertilization followed a higher lodging resistance than those plants from other treatments. So, based on these results, the further study is need to illustrate the details.

Conclusion

The results of this study suggest that K application significantly improved the agronomic traits, mechanical characteristics and biochemical composition, enhancing the lodging resistance and increasing yield of soybean in relay strip intercropping system. The basal stem diameter, stem breaking strength and lignin concentration are the critical factor in reducing lodging of soybean in relay strip intercropping system. Further research on the mechanism of K affects the growth development and the lodging resistance of soybean needs to be developed for this cropping system.

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