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Full Length Research Paper

Effect of phosphorus and potassium nutrition on growth and yield of soybean in relay strip intercropping system

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A field experiment was conducted to determine the effect of Phosphorus (P) application (0, 8.5, 17.0 and 25.5 kg ha^{-1}) and Potassium (K) application (0, 37.5, 75.0 and 112.5 kg ha^{-1}) on growth and yield of soybean (*Glycine max* (L.) Merr.) in relay strip intercropping system. The plant height, stem diameter, branch number and leaf area increased at first and then decreased with the increment of P application, but the performance of lodging rate showed oppositely. By applying K from 0 to 112.5 kg K ha^{-1}, plant height, lodging rate, unfilled pod ratio, and 100 seeds weight were significantly reduced, while pods per plant, seeds per pod, and harvest index remarkably increased. The Highest benefit in growth and seed yield was obtained at rates of 17.0 and 112.5 kg ha^{-1} for P and K, respectively. Application of 17.0 kg P ha^{-1} at the rate of 112.5 kg K ha^{-1} gave 18.5, 13.7, and 4.0% higher seed yield than its application at rates of 0, 37.5, and 75 kg K ha^{-1}, respectively. In conclusion, the findings suggested that the combination of P (17.0 kg ha^{-1}) and K (112.5 kg ha^{-1}) can maximize productivity of soybean in the relay strip intercropping system.

Keywords: Phosphorus, potassium, growth, yield, relay strip intercropping soybean.

INTRODUCTION

The population of the world is increasing at a rapid rate of 1.7% annually, resulting in an imbalance of food supply and demand. Increasing the multiple crop index of land is particularly important for the development of grain production. Intercropping is the effective mean for increasing the income of a farming community as it helps in better utilization of resources and ensures higher returns per unit area and time (Roy et al., 1981). Relay strip intercropping, which is one type of multiple cropping systems and can increase total yield per land area, compared to monocultures of the same crops, has been practiced traditionally by large-scale farmers in China (Yan et al., 2010). In particular, cereal and legume relay strip intercropping is recognized as a common cropping system throughout China. Typically, cereal crop such as maize (*Zea mays*) is dominant crop species, whereas legume crop such as soybean (*Glycine max* (L.) Merr.) is the associated plant species. Since the 1970's, the relay strip intercropping system has being developed widely in the South West of China; the system is one of the important agricultural systems for meeting the local food needs and ensuring food security in China. In this system, the soybean seedling grown in the condition of shading by maize, maize form relatively higher canopy structures than soybean and the roots of maize grow to a greater depth than those of soybean. This indicates that the component crops probably have differing spatial and temporal use of environment resources such as water, nutrients and radiation (Willey, 1990). As sunlight penetrates a canopy, not only the level of light decrease, but the red/far red light (R/FR) declines because of greater absorption of R vs. FR light by leaves of maize (Holmes and Smith, 1977). On the other hand, maize and

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soybean have differing requirement in environment resources, especially on the nutrients. As a note of caution, however, the soybean is tending to be ignored in fertilization application as its nitrogen fixation in conventional practice. So, the growth of soybean is weak (higher plant height and thinner stem diameter) and easier to lodging, which resulted in the lower component of yield and seed yield.

Fertilization could adversely affect the growth, yield and yield components of soybean. Nutrient deficiency during the plant growth stage decreases seed yield, and seed number and size (Desclaux et al., 2000; Larry et al., 1986; Rebafka et al., 1993; Westgate and Peterson, 1993), but the magnitude of effects vary with the variety and quantity of the fertilizer (Pandey et al., 1984a). Phosphorus (P) and Potassium (K), as two essential mineral nutrients, are required in relatively large amounts to maintain growth and play a central role in improving crop yield and quality (Raghothama, 1999; Abel et al., 2002). P deficiency is invariably a common crop growth and yield-limiting factor in unfertilized soil, especially in soils high in calcium carbonate, which reduces P solubility (Ibrikci et al., 2005). Grain and biomass yields, number of grains ear^{-1} and number of rows ear^{-1}, plant height and P uptake efficiency of soybean increases at high level of P application (Manje et al, 2011; Sahoo and Panda, 2001). Plants cannot complete a normal life cycle without sufficient K. Plants grown for food take up and use large quantities of K, P and K deficient plants often have slow growth, poor drought resistance, weak stems, and are more susceptible to lodging and plant disease (Jack and Sara, 2001; Xu, 2011). Early studies also recognized that lodging can affect the growth development and reduce yield by as much as 22% (Noor and Caviness, 1980), the lodging decreased with the reduced plant height and wider stem diameter (Nagata, 1968). Reduced plant height and increased stem diameter are recognized as some effective means of reducing or eliminating lodging (Cooper, 1981; Mancuso and Caviness, 1991). Csatho (1991) and Mulder (1954) determined that appropriate fertilizer application can improve the growth of crops and decrease the lodging tendencies in different crop varieties. Role of K for increased resistance to lodging has been well documented in different crops such as maize (Csatho, 1991); wheat (Khurana and Bhaya, 1990) and oilseed rape (Sharma and Kolte, 1994). The previous results indicated the significance of applying P and K rationally to improve the growth and yield of soybean in this system. P and K interaction is an important phenomenon as deficiencies of both the nutrients are widespread in Chinese soils particularly in intensively cropped areas, especially on the relay strip intercropping and intercropping system. P and K show synergism (Han et al., 2005). Application of higher doses or presence of higher levels of either of them in soil may increase or enhance the availability of the others. P and K interaction is designated as ‘P induced K efficiency’ in many crops (Sardans et al., 2008), but such information related to this interaction in relay strip soybean is scanty. Although, the positive effects of P and K are obviously in crop, the intensive and excessive use of P and K fertilizers have resulted in the accumulation of P and K in soils (Uddin, 2001), the increased accumulation of P and K in agricultural soils is closely related to freshwater eutrophication. Optimal P-fertilization and K-fertilization in the maize-soybean relay intercropping systems is one of the effective measures to improve crop yield and to protect the environment from surface water eutrophication.

In recent years, the agricultural scientists and extension officers provide some information of planting technology to farmers in P and K application under multiple cropping systems, and the preceding limited literature suggests that P and K fertilizer affect plant growth and yield. However, the detailed studies are lacking on the interactive effects of P and K fertilizer on soybean growth and yield in relay strip intercropping system. For sustainable high crop production in this system, P and K fertilizer are indispensable. So, the aims of this study were to investigate the impacts of different P and K fertilizer on the growth and yield of soybean in relay strip intercropping system.

MATERIALS AND METHODS

Site description

The field experiment was conducted at experimental site of Shehong county, Sichuan Province (30°52' N, 105°23' E), China during summer 2008 in the system of maize-soybean relay strip intercropping. Shenhong is located at an altitude of 510 m above mean sea-level with annual rainfall of 950 mm. The soil 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, 51.24 mg kg^{-1}, 1.82, 1.32, 14.96 and 12.04 g kg^{-1}, respectively. Soil physiochemical properties such as texture, organic matter, available N, P, and K, total N, P, and K were determined according to standard procedures (Soltanpour, 1985; Gee and Bauder, 1986).

Experimentation

The experiment consisting of 4 levels of P (0, 8.5, 17.0, and 25.5 kg P ha^{-1}) and 4 levels of K (0, 37.5, 75.0, and 112.5 kg K ha^{-1}) making 16 treatments combinations was laid out in a two-factor randomized block design with 3 replications. A uniform does of 60 kg ha^{-1} nitrogen was applied through urea, sulfate K and calcium superphosphate. P through calcium superphosphate and K through sulfate K were applied as per treatment. All of nitrogen, P and K were drilled at the time of 15 days after germination. Gongxuan 1 soybean cultivar was sown in June 3, 2008 at 20 cm apart using seed rate of 45 kg ha^{-1}, and the desired densities (1.01 ×10^{5} plant ha^{-1}) were obtained by thinning at the early vegetative V2 stage (2-trifoliolate). In the relay strip intercropping system (maize relay soybean), 1.14 m wide strips were prepared, the maize was sown on 0.2 m wide area of the strips in the beginning of April, the

Figure 1. In this experiment, Growing of soybean seedling with maize (A and B), only soybean grows in the field after harvesting the maize (C and D). 1.14 m wide strips were prepared in the field. On these strips, the maize for 1 row with 2 plants per hole was sown on 0.2 m wide area of the strips in the end of March; the soybean for 2 rows with 3 plants per hole was sown on 0.93 m wide area of the strips in the beginning of June. Finally, the soybean was harvested at R8 stage in the end of October (D).

soybean was sown on 0.93 m wide area of the strips in the beginning of June. The size of each treatment was 1.13 × 8.00 m. On these strips, each treatment consisted of 2 rows, 8 m long with row to row distance of 46.5 cm for soybean. On the strip of maize, each treatment consisted of 1 row, and the distance was 23.3 cm between maize and soybean (Figure 1). The plant height, stem diameter, number of branches per plant, leaf area plant^{-1}, and lodging rate were measured at R5 stage (The beginning seed stage). The relay strip intercropping soybean was harvested at R8 stage (the full ripe stage) for seed yield and component of yield. The plants were cut off at the cotyledon level and separated into stems plus petioles, leaves, pod walls, and seeds. All the samples were oven-dried at 70°C for 48 h to weigh the biological/biomass yield. Data on plant height, stem diameter, number of branches per plant, leaf area plant^{-1}, lodging rate, grain yield, number pods per plant, seeds per pod, 100 seeds weight and harvest index were recorded/calculated as follow.

Growth analysis

Ten plants were randomly selected from each treatment, and plant height (from base to top), stem diameter and number of branches were measured and then averaged. The stem diameter was measured with the help of vernier caliper.

Leaf area Plant^{-1} (cm^2)

Ten plants were randomly selected from each treatment and leaf area of leaves of ten plants was measured with the help of Handheld Laser Leaf Area Meter (CI-203) and averaged.

Lodging rate (%)

For recording plant in lodging, the soybean plant was counted, which the angle of main stem and ground is lower than or equal to 30°C at the R5 stage from each treatment. Lodging rate was calculated using the following formula:

Lodging rate (%) = Plant number of each treatment in lodging/the number of all plants in each treatment × 100

Seed yield (kg ha^{-1})

For recording seed yield, the soybean from each subplot at maturity

Table 1. Summary of analysis of variance (ANOVA) for various parameters.

Parameter	Phosphorus source (P)	Potassium source (K)	P × K
Plant height	ns	*	ns
Stem diameter	ns	*	ns
Number of branches	*	*	ns
Leaf area	ns	ns	*
Lodging rate	*	*	ns
Seed yield	*	*	ns
Unfilled pod ratio	*	*	ns
100 seeds weight	*	*	ns
Pods per plant	*	*	*
Seeds per pod	*	*	*
Harvest index	*	*	*

*denotes significant at $P \leq 0.05$, and ns refers to not significant.

were harvested, husked, dried and threshed. Seed yield was recorded and converted to kg ha^{-1} by using the formula:
Seed yield (kg ha^{-1}) = kg seed yield m^{-2} × 10,000 m^{2}.

Unfilled pod ratio (%)

Unfilled pod ratio was calculated based on the following formula:

Unfilled pod ratio (%) = Unfilled pod number of ten plants/ Total pod number of ten plants

Yield component

Ten plants were randomly selected from each treatment, pod and seed number of ten plants were counted, and then mean pods per plant, seeds per pod and seeds per plant were calculated. The seeds per pod were calculated by the following formula: Seeds per pod-seeds number of ten plants/ pod number of ten plants.

100 seeds weight was taken at random from the seeds of each treatment using electronic balance. This was repeated three times and then average weight per 100 seeds was calculated and recorded.

Harvest index (%)

Harvest index was calculated using the following formula:

Harvest index (%) = Seed yield (kg ha^{-1})/ (Biological/biomass yield (kg ha^{-1}) ×100

Data analysis

The data of plant height, average, seed yield, and component of yield were statistically analyzed by factorial ANOVA to determine the effects of P, K and their interactions. Regression analysis was also performed to determine the relationships between variables. The comparisons between treatments were evaluated with Fisher's LSD using SPSS software. A brief summary of ANOVA for all parameters is presented in Table 1.

RESULTS

Soybean growth

The plant height and stem diameter of relay strip intercropping soybean increased at first and then decreased with the increasing amount of P application. The highest plants of 104.1 cm height and stem diameter of 0.86 cm (Table 2) were noted when soybean was planted at levels of P (17.0 kg ha^{-1}). Shorter plants (97.3 to 99.7 cm) and wider stem diameter (0.86 to 0.91 cm) were observed in K-fertilization treatment when compared with taller plants (106.1 cm) and thinner stem diameter (0.74 cm) in the zero-K control, respectively. The plant height of soybean was significantly decreased with the increase of K application in this system, but the performance was different in stem diameter, the maximum stem diameter (0.91 cm) was retained at the level of 75.0 kg K ha^{-1}.

Both P and K significantly affected the number of branches of soybean, but the interaction was not significant (Table 3). The branch number per plant ranged from 5.0 to 6.5 and 4.7 to 6.5 with the P and K application, respectively. The maximum branches number per plant (6.5) were observed at the level of 17 or 75.0 kg K ha^{-1}, 38.3 or 30.0% higher than zero-P control and zero-K control, respectively. For P application, the maximum leaf area (62.6 cm^{2}) for relay strip intercropping soybean was recorded at the level of 17.0 kg P ha^{-1}, while minimum leaf area (55.4 cm^{2}) was recorded at the zero-P control (Table 3). For K application, maximum leaf area (70.7 cm^{2}) was worked out to be 75.0 kg K ha^{-1}, followed by 37.5 kg K ha^{-1} (59.4 cm^{2}), while the lowest leaf area of 53.8 cm^{2} was calculated for the zero-K control. The interaction of P × K indicated that leaf area increased at first and then decreased with increase in P applied with K (75.0 kg ha^{-1}), but there was no obvious regularity in P application treatment with K (0, 37.5, 112.5

Table 2. The effect of P and K application on plant height and stem diameter of soybean in relay strip intercropping system.

Amount of P application (kg ha^{-1})	Plant height (cm) at different rates of K fertilizer				
	0	37.5	75	112.5	Mean
0	105.1	101.7	94.9	95.8	99.4^a
8.5	111.8	105.9	92.4	99.8	102.5^a
17	105.0	109.4	103.8	98.3	104.1^a
22.5	102.7	103.2	98.3	104.8	102.2^a
Mean	106.1^a	105a^b	99.7b^c	97.3^c	
$LSD_{0.05}$	P＝0.94; K＝4.28				
Stem diameter (cm) at different rates of K fertilizer					
0	0.77	0.86	0.85	0.84	0.83^a
8.5	0.66	0.77	0.95	0.96	0.83^a
17.0	0.80	0.89	0.93	0.83	0.86^a
22.5	0.71	0.82	0.92	0.82	0.82^a
Mean	0.74^b	0.83^a	0.91^a	0.86^a	
LSD0.05	P = 0.16; K = 4.11				

Mean values of the same category followed by different letters are significant at P≤0.05 using LSD.

Table 3. The effect of P and K application on number of branches and leaf area of soybean in relay strip intercropping system.

Amount of P application (kg ha^{-1})	The number of branches (plant^{-1}) at different rates of K fertilizer				
	0	37.5	75	112.5	Mean
0	4.2	4.8	4.8	5.0	4.7^b
8.5	4.8	5.0	6.0	5.8	5.4a^b
17	6.2	6.3	7.7	5.7	6.5^a
22.5	4.7	4.7	7.3	4.5	5.3^b
Mean	5.0^b	5.2^b	6.5^a	5.3^b	
LSD0.05	P = 5.05; K = 4.30				
Leaf area (cm^2) at different rates of K fertilizer					
0	53.0	58.0	67.5	43.3	55.4^a
8.5	62.2	65.6	78.2	41.4	61.9^a
17	33.2	56.4	88.5	72.2	62.6^a
22.5	66.7	57.6	48.5	61.5	58.6^a
Mean	53.8^b	59.4a^b	70.7^a	54.6^b	
$LSD_{0.05}$	P = 0.18; K = 1.03; P × K＝3.6				

Mean values of the same category followed by different letters are significant at P≤0.05 using LSD.

kg ha^{-1}).

The lodging rate of soybean was significantly different among treatments (Table 4), which was significantly reduced with the increment of K application. The lowest lodging rate (38.10%) was record at the treatment of 112.5 kg K ha^{-1}, which was 27.8% lower than the levels of zero-K control. For P application, lower lodging rate (42.7%) was attained at the treatment of 17.0 kg P ha^{-1}, when compared with zero-P control's 46.4% lodging rate. Nevertheless, the interaction between P and K was not significant.

Yield of relay strip intercropping soybean and its components

The highest seed yield (2695 kg ha^{-1}), pods per plant (81.6), seeds per pod (1.28), harvest index (42.8%) were

Table 4. The effect of P and K application on lodging rate and seed yield of soybean in relay strip intercropping system.

Amount of P application (kg ha^{-1})	Lodging rate (%) at different rates of K fertilizer				
	0	37.5	75	112.5	Mean
0	55.75	52.19	44.17	37.63	47.40^{a}
8.5	51.58	48.04	41.11	36.63	44.30^{b}
17	49.53	44.08	41.39	35.86	42.70^{b}
22.5	54.36	51.10	46.21	42.42	48.50^{a}
Mean	52.80^{a}	48.90^{b}	43.20^{c}	38.10^{d}	
$LSD_{0.05}$	P = 13.2; K = 75.2				
	Seed yield (kg ha^{-1}) at different rates of K fertilizer				
0	2203	2323	2424	2560	2378^{c}
8.5	2258	2386	2532	2641	2454b^{c}
17	2389	2490	2723	2832	2609^{a}
22.5	2313	2457	2610	2748	2532^{b}
Mean	2291^{d}	2414^{c}	2572^{b}	2695^{a}	
$LSD_{0.05}$	P = 49.2; K = 156.5				

Mean values of the same category followed by different letters are significant at P≤0.05 using LSD.

produced by relay strip intercropping soybean at the rate of 112.5 kg K ha^{-1} (Tables 4, 5, 6 and 7). The lowest seed yield (2291 kg ha^{-1}), pods per plant (72.1), seeds per pod (1.20), harvest index (40.0%) were recorded in the zero-K control. For P treatment, the highest average seed yield (2609 kg ha^{-1}), 100 seeds weight (19.58 g) and pods per plant (78.2) were recorded when soybean was planted at the amount of 17.0 kg P ha^{-1}. The lowest seed yield (2378 kg ha^{-1}), seeds per pod (1.20) and harvest index (40.2%) were obtained at the zero-P control. The treatment of 112.5 kg K ha^{-1} produced the highest seed yield of 2832 kg ha^{-1} at the levels of P (17 kg ha^{-1}), which was 18.5% higher than that of zero-K control. On the other hand, the lowest 100 seeds weight (19.34 g) and pods per plant (74.4) were observed when soybean was planted the highest P application (22.5 kg ha^{-1}), while less unfilled pod ratio of 5.2% was obtained at application of 17.0 kg P ha^{-1} (Table 6).

Interaction of P × K indicated that increasing amount of K application from 0 to 112.5 kg ha^{-1} increase pods per plant and seeds per pod significantly (Table 6), similar trend was also observed at the rate of P application from 0 to 17 kg ha^{-1}. The harvest index increased first and then decreased with increment of P application when at the rate of K application (0, 75, 112.5 kg ha^{-1}), while at the level of 37.5 kg K ha^{-1}, the harvest index increased with increasing of P application amount (Table 7).

DISCUSSION

P and K are two of the most essential and indispensable nutrients for crop growth. With respect to growth character, it was observed that the plant height and leaf area increased significantly with P application. Plant height increased with increased P application up to 17 kg P ha^{-1}. This could be due to the fact that P being essential constituent of plant tissue significantly influences the plant height of crop (Kumar and Chandra, 2008; Shahid et al., 2009) were also observed significant improvement in plant height of soybean by P-fertilization. The plant height of relay strip intercropping soybean decreased markedly with increased K application up to 112.5 kg K ha^{-1}. The present findings are in unconformity with the results obtained by Adel et al. (1994) who reported increase in plant height of soybean at high than at low K application. The possible reason was that K application improves the growth development of soybean, increased the uptake efficiency of soybean nutrients, and furthered the growth of other sections (that is, wider stem diameter, Table 2; more branch number, Table 3).

The P and K application improved the lodging resistance of soybean, reduced the lodging rate (Table 4). These results are in confirmation with the reported by (Parks, 1985) who postulated that lodging resistance is primarily governed genetically and adequate K application further decrease. According to the correlation analysis, the lodging rate was significantly (P<0.05) positively correlated with plant height, but significantly (P<0.01) negatively correlated with stem diameter (Table 8). Compared with the treatment of zero-K control, the K application increased the stem diameter, lowered the plant height, and reduced the lodging rate. Wakhloo (1975) who also observed that the lodging resulted from the interactive effects by environmental and soil conditions, plant type and nutrient management, the

Table 5. The effect of P and K application on unfilled pod ratio and 100 seeds weight of soybean in relay strip intercropping system.

Amount of P application (kg ha^{-1})	Unfilled pod ratio (%) at different rates of K fertilizer				
	0	37.5	75	112.5	Mean
0	6.4	5.7	5.2	4.8	5.6^{a}
8.5	6.2	5.5	5.0	4.6	5.3^{b}
17	6.1	5.3	5.0	4.3	5.2^{c}
22.5	6.5	5.4	5.2	4.3	5.3^{b}
Mean	6.3^{a}	5.5^{b}	5.1^{c}	4.5^{d}	
$LSD_{0.05}$	P = 7.1; K = 170.0				
100 seeds weight (g) at different rates of K fertilizer					
0	19.60	19.41	19.30	19.27	19.39b^{c}
8.5	19.77	19.42	19.30	19.21	19.43^{b}
17	19.89	19.76	19.45	19.22	19.58^{a}
22.5	19.68	19.37	19.18	19.12	19.34^{c}
Mean	19.74^{a}	19.49^{b}	19.31^{c}	19.20^{d}	
$LSD_{0.05}$	P = 6.0; K = 30.5				

Mean values of the same category followed by different letters are significant at P≤0.05 using LSD.

Table 6. Effect of P and K application on pods per plant and seeds per pod of soybean in relay strip intercropping system.

Amount of P application (kg ha^{-1})	Pods (plant^{-1}) at different rates of K fertilizer				
	0	37.5	75.0	112.5	Mean
0	71.0	74.5	77.0	81.5	76.0^{c}
8.5	72.1	76.2	78.8	82.8	77.5^{b}
17	74.0	76.6	78.9	83.2	78.2^{a}
22.5	71.2	72.5	74.7	79.1	74.4^{d}
Mean	72.1^{d}	74.9^{c}	77.3^{b}	81.6^{a}	
$LSD_{0.05}$	P = 25.9; K=148.9; P × K= 4.9				
Seeds (pod^{-1}) at different rates of K fertilizer					
0	1.18	1.19	1.21	1.21	1.20^{c}
8.5	1.18	1.2	1.24	1.23	1.21^{c}
17	1.21	1.22	1.32	1.32	1.27^{b}
22.5	1.23	1.3	1.35	1.35	1.31^{a}
Mean	1.20^{c}	1.23^{b}	1.28^{a}	1.28^{a}	
$LSD_{0.05}$	P=18.5; K=12.0; P × K=4.9				

Mean values of the same category followed by different letters are significant at P≤0.05 using LSD.

diameter of stem is reduced making the plant susceptible to lodging in K-deficient plant. Thus, under optimal fertilizers application such as occurred for this study, a viable means to reducing lodging is to applied the P of 17.0 with 112.5 kg K ha^{-1}.

Leaf area, 100 seeds weight, pods per plant and seed yield reached maximum levels when relay strip intercropping soybean was planted at the treatment of 17 kg P ha^{-1} (Tables 3, 4, 6 and 7). The possible reason might be that at the levels of P application (17 kg P ha^{-1}) most plants were vigorous and absorbed the nutrients more efficiently, but when the amount of P application was increased above 17 kg P ha^{-1}, a problem of growth limited that may have resulted in lower leaf area, and subsequently 100 seeds weight, pods per plant and seed yield. Our results are in agreement with those of Pauline

Table 7. Effect of P and K application on harvest index of soybean in relay strip intercropping system.

Amount of P application(kg ha^{-1})	Harvest index (%) at different rates of K fertilizer				
	0	37.5	75.0	112.5	Mean
0	39.0	40.0	40.4	41.3	40.2c
8.5	39.6	40.4	41.3	41.9	40.8b
17.0	40.9	41.2	43.0	43.6	42.1a
22.5	40.3	41.4	42.5	44.3	42.2a
Mean	40.0d	40.7c	41.8b	42.8a	
$LSD_{0.05}$	P=22.7; K=34.1; P × K = 2.3				

Mean values of the same category followed by different letters are significant at P≤0.05 using LSD.

Table 8. Correlation analysis on some indexes of soybean in relay strip intercropping system.

Indexes	Plant height	Stem diameter	Number of branches	Leaf area	Lodging rate
Stem diameter	−0.56*				
Number of branches	−0.12^{ns}	0.64**			
Leaf area	−0.10^{ns}	0.06^{ns}	0.14^{ns}		
Lodging rate	0.50*	−0.63**	−0.42^{ns}	−0.12^{ns}	
Seed yield	−0.36^{ns}	0.60*	0.51*	0.23^{ns}	−0.85**

*denotes significant at P≤0.05, **denotes significant at P≤0.01, and ns refers to not significant.

et al. (2010), Kamara et al. (2008), and Aise et al. (2011) who reported similar findings of higher leaf area, 100 seeds weight, pods per plant and seed yield of soybean under the condition of the proper P application. The decrease in leaf area, 100 seeds weight, pods per plant and seed yield at the lowest and highest P application was most likely due to the growth development of soybean was influenced by nutrient deficiency or nutrition surplus. Our results are in confirmation with reports by Bly et al. (1997), Alpha et al. (2007) who found that proper P improve the shoot P uptake and increase shoot dry matter weight, 100 seeds weight, pods per plant and yield. Chiezey et al. (2009) suggested that the application of P stimulated leaf expansion, hence more light interception for photosynthetic activity, high assimilated accumulation and seed yield, pod yield and 100 seeds weight which are important determinants of seed yield increased with P application. These resulted in increased seed yield. On the other hand the decrease in leaf area, 100 seeds weight, pods per plant and seed yield at low P application might be due to the shortage of nutrients availability to plants due to the strong competition among the plants (Duncan, 2002) that limited the growth improvement of soybean. Leaf area in relay strip intercropping soybean increased with the application of 37.5 and 75.0 kg K ha^{-1} as compared to smaller leaf area with 112.5 kg ha^{-1} and in zero-K control. Increase in soybean leaf area with application of proper K is also reported by Jaspinder (1994). Plots applied with 112.5 kg K ha^{-1} produced highest seed yield, pods per plant, seeds per plant and harvest index (Tables 4, 7, 8 and 9). Similar results were reported by Sale and Campbell (1986) that when the K supply was increased well the level necessary to produce maximum seed yield. The increase in pods per plant, seeds per plant and seed yield in the plots applied with 112.5 kg K ha^{-1} might be the possible cause of increase in harvest index of relay strip intercropping soybean.

The unfilled pod ratio was significantly lower at 17.0 kg P ha^{-1} than other treatments (Table 5), K application significantly reduced the unfilled pod ratio, increased the effective pod of soybean. The 100 seeds weight and unfilled pod ratio are all decreased with the increase of K application amount (Tables 5 and 6). Our results are in line with those of Tran et al. (2006) and Sale et al. (1986) who observed decline in 100 seeds weight and unfilled pod ratio of soybean with increasing K application. Plots applied with K fertilizers had higher pods per plant; seeds per plant, seed yield and harvest index (Tables 4, 7, 8 and 9). Fabián et al. (2009) and Mohammadi (2009) also showed that K application to soybean increased yield and yield components over the zero K-control. In this study, the yield losses started occurring at the stage of growth of soybean, such as the formation of plant height, stem diameter, and branch number. The stem diameter and number of branches was significantly positively correlation with yield (Table 8), but the lodging rate gave significantly negatively correlation with yield. So, in this system, the role of P and K in enhancing the growth of soybean, reducing the lodging rate, and increasing the yield of soybean shown in this study.

CONCLUSION

Growing soybean at 17.0 kg P ha^{-1} and application of K-fertilization had the maximum positive impact on soybean growth and grain in the maize-soybean relay strip intercropping system. At this level of P application, the application of 112.5 kg K ha^{-1} gave the highest seed yield, pods per plant, seeds per pod and harvest index, and the lowest lodging rate of soybean, while 0 kg K ha^{-1} had the poorest performance. Overall, the treatment of applied 112.5 with 17.0 kg P ha^{-1} was the most effective for the growth and high yield of relay strip intercropping soybean, followed by 75.0 kg K ha^{-1}, and then 37.5 kg K ha^{-1}. Further research on the mechanism of P and K affect the growth development and yield of soybean need to be developed for this cropping system in various agro-climatic zones of South west of China.

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