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Growth response of *Bradyrhizobium* inoculated soybean grown under maize intercropping systems, and P and K fertilization

Daniel Nyoki, Patrick A. Ndakidemi*

School of Life Science and Bio-engineering, The Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania

Key words: Growth response, *Bradyrhizobium,* Soybean, Intercropping systems, Fertilization

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Abstract

The field experiment was carried out for two consecutive years to assess the effects of cropping systems, *Rhizobium* inoculation supplemented with P and K on growth performance of soybean. The experiment was laid out in split-split plot design with the main plots comprised of Rhizobia inoculation (with and without). The sub plots comprised of three cropping systems and the sub-sub plots having seven fertilizer levels (kg ha^{-1}): Control, 20, 40 K, 26, 52 P, 26 P + 20 K and 52 P + 40 K. The experiment was replicated thrice. The results indicated that both treatments influenced most of the growth parameters of soybean assessed. Over un-inoculated treatments, Rhizobia inoculation significantly improved the growth of all parameters of soybean in this study. Similarly, P and K fertilization improved the growth of soybean over the control. Most of the parameters performed supper in plots treated with Rhizobia inoculation supplied with 26, 52 P and 20 K + 26 P kg ha^{-1} levels of P and K. The positive interactive effects of cropping systems, *Rhizobium* inoculation and P and K supplementation was observed on different growth parameters assessed. The positive interaction indicated the importance of these inputs and treatments for improving growth of crops and ultimately final yield in the study area.

* **Corresponding Author:** Patrick A. Ndakidemi ✉ ndakidemipa@gmail.com

Introduction

In recent years, there has been increased interest in production of Soybean [*Glycine max* (L.) Merr.] and its yield have substantially increased since 1961 (Lobell and Field, 2007). The crop has been gaining global attention due to its health, nutritional and economical importance to human (Mateos-Aparicio, *et al*., 2008). It is also used as animal feeds (Undie *et al*., 2012) and for improvement of soil fertility (Dwivedi *et al*., 2015). To achieve the desired yield performance, the crops must grow vigorously and free from biotic and abiotic stress. Among many other factors, yield performance of crops is influenced by plant growth. There are diverse factors that may affect plant growth including cropping patterns and soil nutrition among others. Intercropping is one of the cropping patterns which may affect crop growth.

Mineral elements such as N, P and K play important roles in plant growth (Nyoki and Ndakidemi, 2014a). These macronutrients are required in relatively large amount by plants. Phosphorus is used for various plant functions including energy transfer, photosynthesis, translocation of sugars and starches as well as movement of nutrients within the plant (Brady, 2002; Shahid *et al*., 2009). Potassium plays a number of vital physiological processes such as activation of several enzymes, synthesis and degradation of carbohydrates, production of proteins as well as regulation of stomata pores for gas exchange and photosynthesis (Lissbrant *et al*., 2009). Nitrogen is the key element for plant growth as well as yield performance (Nyoki and Ndakidemi, 2014b).

Legumes are good at fixing own nitrogen and contribute to the soil fertility and nutrition through decomposition of crop litter and release of fixed nitrogen from the root nodules. Vincent *et al*. (1979) previously studied and found that unavailability of specific strain of rhizobia reduced growth of leguminous crops. Several studies on rhizobia inoculation have reported that inoculated legumes improved growth over the control (Yamanaka *et al*., 2005; Bambara and Ndakidemi, 2009; Bambara and Ndakidemi 2010).

It has been reported that major elements (N, P and K) are continuously declining in East Africa. The current study aimed at investigating and exploration of soybean growth potentials under cereal-legume intercropping, rhizobia inoculation and P and K fertilization.

Material and methods

Experimental Design and Treatments

The field experiment was carried out at Tanzania Coffee Research Institute (TaCRI) farm for two consecutive years (2015 and 2016). The experiment was laid out in split-split plot design with 2 x 4 x 7 factorial arrangements and replicated thrice. The plot size was 3 x 3 m, with main plots having two rhizobia inoculation treatments, while the sub plots comprised: Maize (sole crop) at a spacing of 75 x 60 cm; Soybean (sole crop) at a spacing of 75 x 40 cm; Maize/soybean (intercropping system) at a spacing of 75 x 60 cm and 75 x 20 cm, Maize and soybean respectively; and the last cropping system was Maize/soybean (intercropping system) at a spacing of 75 x 60 cm and 75 x 40 cm, Maize and soybean respectively. The sub-subplots were assigned the following fertilizer levels (kg ha^{-1}): control; 20 K; 40 K; 26 P; 52 P; 26 P + 20 K; 52 P + 40 K.

Data collection

The growth and development parameters of soybean which were measured included: plant heights (H) measured at different stages of the plants growth, number of leaves per plant; leafarea, stemgirth (SG). Plant height was measured using a meter ruler, while the leaf area (cm^2) was calculated as the product of the total length and width at the broadest point of the longest leaf on the plant. Stem girth (cm) was measured with digital veneer calliper at physiological maturity.

Statistical analysis

The collected data was analysed using statistical software called STATISTICA. The statistical analysis was performed using the 3-way analysis of variance (ANOVA) in factorial arrangement. The fisher's least significance difference (L.S.D.) was used to compare treatment means at p = 0.05 level of significance (Steel and Torrie, 1980).

Results

The current study assessed how different variables are affected by cropping systems, Rhizobia inoculation and fertilization with P and K. The results showed that some of the growth parameters were positively influenced by treatments applied. Some of the factors had no significant effect on parameters measured. Therefore, we only report the significant data.

Plant height

The results presented in study showed that all the factors tested had the significant effects on plant height (Table 1). Cropping systems significantly affected the height of soybean plants where by in all cases sole soybean (SB) recorded the lowest plant height from 2, 4 and 6 weeks after planting (WAP) for the two cropping seasons. The highest plant height was recorded in the soybean intercropped with maize at narrower spacing of M+B (A) regardless of time taken from planting to measurement.

However, the intercropped soybean statistically had plants of the same height measured at 6WAP which were significantly higher compared with sole bean (SB) (Table 1). Furthermore, the current study showed that rhizobia inoculated soybean significantly increased plant height over the un-inoculated plots measured at 2, 4 and 6 WAP for the two cropping seasons (Table 1). Fertilization of crops with P and K significantly increased the height of soybean measured at 2, 4 and 6 WAP over the control for the two cropping seasons (Table 1). In the first cropping season (2015), the two levels of P (26 and 52 kg ha^{-1}) significantly produced taller plants over all other treatments and the control.

In the second cropping season, 52 P; 20 K + 26 P and 40 K + 52 P kg ha^{-1} significantly produced taller plants compared with the other treatments. In all measurements, the control plots gave the sorter plants relative to other fertilizer applied plots for the two cropping seasons (Table 1).

Table 1. Effects of cropping systems, rhizobia inoculation, and P and K fertilization on plant height.

Treatments	Plant Height (cm) 2WAP		Plant Height (cm) 4WAP		Plant Height (cm) 6WAP	
	2015	2016	2015	2016	2015	2016
Cropping System						
SB	13.44±0.31a	15.09±0.22b	20.94±0.51b	24.14±0.39c	26.08±0.57b	31.42±0.67b
M+B(A)	13.99±0.34a	15.77±0.31a	22.34±0.55a	27.71±0.59a	28.12±0.66a	36.37±0.90a
M+B(B)	13.88±0.32a	14.90±0.31b	21.72±0.55ab	25.34±0.48b	27.49±0.79a	34.72±0.92a
Rhizobia						
With	15.02±0.21a	16.25±0.21a	23.92±0.38a	27.11±0.46a	30.58±0.43a	36.38±0.59a
With out	12.52±0.21b	14.25±0.19b	19.41±0.28b	24.35±0.35b	23.88±0.30b	31.96±0.75b
Fertilizers (kg ha^{-1})						
0	11.59±0.52c	13.41±0.30c	17.59±0.52d	22.52±0.42c	25.87±0.79b	33.89±1.51
20K	13.57±0.40b	14.50±0.26b	20.93±0.56c	23.98±0.43b	26.07±0.77b	31.93±1.41
40K	13.76±0.44ab	14.85±0.32b	21.13±0.60bc	25.31±0.73b	28.61±1.11a	33.15±1.50
26P	14.41±0.55a	15.19±0.37b	23.28±0.88a	25.11±0.58b	28.89±1.26a	33.69±1.35
52P	14.44±0.50a	16.26±0.41a	23.22±0.78a	27.48±0.91a	28.93±1.18a	35.94±1.22
20K+26P	12.54±0.42ab	16.44±0.48a	23.21±0.75a	27.65±0.84a	25.88±0.71b	34.37±1.17
40K+52P	13.07±0.48ab	16.13±0.43a	22.30±0.79ab	28.06±0.86a	26.35±1.18b	36.24±1.26
3-Way ANOVA F-statistics						
CroSyt	1.389	6.43**	6.31**	29.19***	10.61***	12.589***
Rhiz	75.482***	92.84***	193.88***	50.40***	327.64***	28.983***
Fert	4.110***	16.22***	22.96***	16.54***	9.25***	1.962
CroSyt*Rhiz	0.843ns	6.97**	3.02ns	5.36**	7.23***	0.887
CroSyt*Fert	0.482ns	0.41ns	0.37ns	0.61ns	0.86ns	1.557
Rhiz*Fert	0.692ns	0.71ns	2.14ns	0.47ns	4.93***	1.597
CroSyt*Rhiz*Fert	0.909ns	0.65ns	1.05ns	1.08ns	2.67**	1.334

Cro Syt: Cropping Systems; Fert: Fertilizers; Rhiz: Rhizobium; SB: Sole soybean; M+B (A): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 20 cm, maize and soybean respectively; M+B (B): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 40 cm, maize and soybean respectively; Values presented are means ± SE; *,**, ***: significant at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ respectively, ns = not significant, SE = standard error. Means followed by dissimilar letter(s) in a column are significantly different from each other at p=0.05 according to Fischer least significance difference (LSD).

Interactive effects of Rhizobia and cropping systems on plant height measured 2 and 4 weeks after planting in 2016 cropping season

The current study showed a significant interaction between Rhizobia and cropping systems on plant height measured 2 and 4 weeks after planting in 2016 cropping season. Rhizobia inoculation influenced the plant height across the cropping systems over un-inoculated plots (Fig. 1A and B). Intercropped soybean with rhizobia inoculation significantly gave taller plants over sole soybean and un-inoculated soybean (Fig. 1A and B).

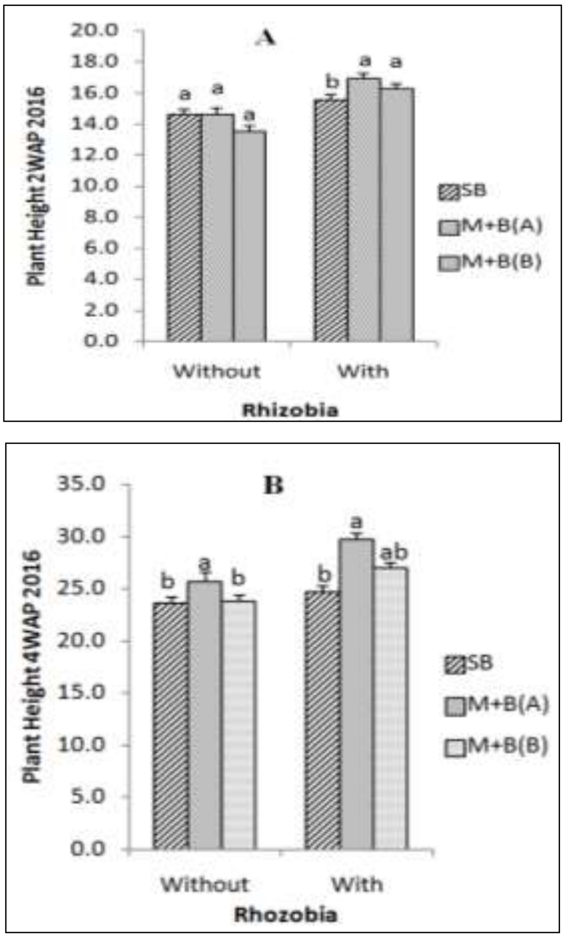

Fig. 1. Interaction between rhizobia and cropping systems on plant height measured 2(A) and 4(B) weeks after planting in 2016 cropping season.

SB: Sole soybean; M+B (A): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 20 cm, maize and soybean respectively; M+B(B): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 40 cm, maize and soybean respectively. WAP = Weeks after planting. Bars followed by similar letter(s) are not significantly different from each other.

Interactive effects of Rhizobia and cropping systems (A) and interactive effects of Rhizobia and fertilizers (B) on plant height measured 6 weeks after planting in 2015 cropping season

Rhizobia inoculation influenced the plant height across the cropping systems over un-inoculated plots (Fig. 2A and B). Intercropped soybean with rhizobia inoculation significantly gave taller plants over sole soybean and un-inoculated soybean (Fig. 2A). In Fig. 2B, inoculation of soybean with rhizobia produced taller plants over un-inoculated plants. Regardless of the applied fertilizers, un-inoculated treatments didn't have significant effect on plant height. However, fertilizer application had significant effects on plant height in rhizobia inoculated soybean (Fig. 2B).

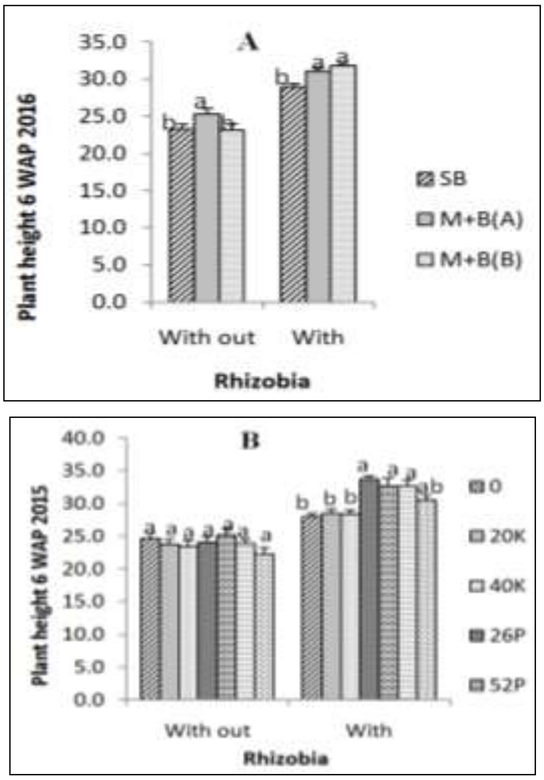

Fig. 2A and B: Interaction between Rhizobia and cropping systems (A) and interaction between Rhizobia and fertilizers (B) on plant height measured 6 weeks after planting in 2015 cropping season.

SB: Sole soybean; M+B (A): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 20 cm, maize and soybean respectively; M+B (B): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 40 cm, maize and soybean respectively. WAP = Weeks after planting. Bars followed by similar letter(s) are not significantly different from each other.

Interactions between Cropping systems, Rhizobia and fertilizers on plant height measured at 6 weeks after planting in 2015 cropping season

There were significant interactions between cropping systems, Rhizobia inoculation and fertilizers on plant height measured at 6 weeks after planting in 2015 cropping season. Rhizobia inoculation significantly increased plant height relative to un-inoculated plots across all the cropping systems.

Generally, the plots treated with 26, 52 P; 26 P +20 K and 52 P + 40 K (kg ha-1) performed better in terms of soybean plant height. Furthermore, whether inoculated or not inoculated intercropped soybean at narrower.

Spacing (M+B (A)) produced significantly taller plants compared with sole soybean (SB) and intercrop at wider spacing M+B (B) (Fig. 3).

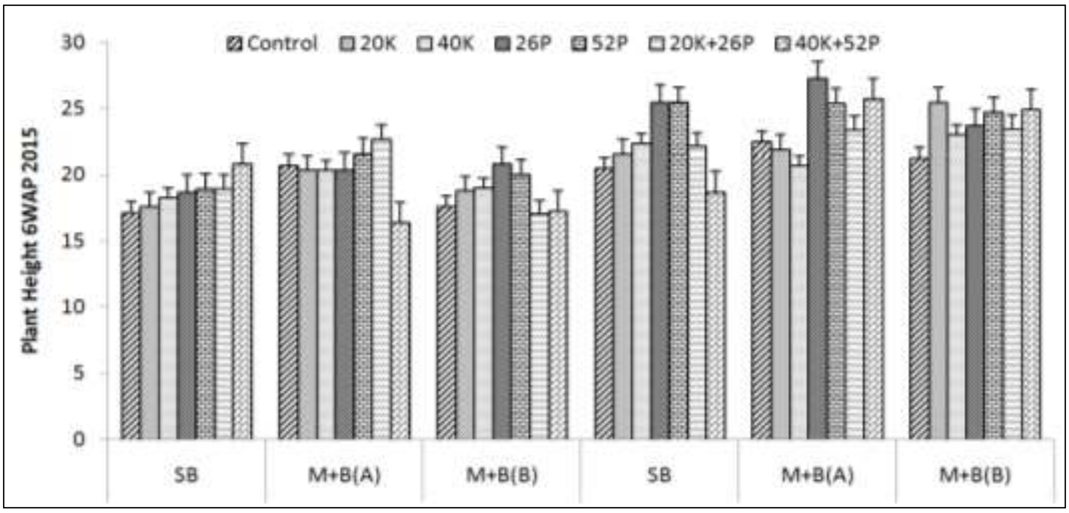

Fig. 3. Interactions between Cropping systems, rhizobia and fertilizers on plant height measured at 6 weeks after planting in 2015 cropping season.

SB: Sole soybean; M+B (A): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 20 cm, maize and soybean respectively; M+B (B): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 40 cm, maize and soybean respectively. WAP = Weeks after planting.

Stem girth

Soybean grown as mono-crop (SB) had significantly greater stem girth compared with those in intercropped plots for the two cropping season. Regardless of the spacing, intercropped soybean gave statistically the same stem girths which are lower than those in mono crop for the two cropping seasons. Similarly, Rhizobia inoculated soybean had significantly greater stem girth compared with un-inoculated soybean for the two cropping seasons. P and K fertilization also increased stem girth over the control. For the two cropping seasons, the plots that received 52 kg P ha-1 resulted in greater stem girth over all treatments (Table 2). The plots treated with 52 kg P ha-1 increased the stem girths by 14 and 30 % from the control in 2015 and 2016 cropping season respectively (Table 2).

The combined fertilizers whether applied at lower dose or doubled dose resulted in statistically the same stem girth which are the same as those recorded in 52 kg P ha-1.

Pant vigour

From the current study, cropping season had no significant effects on the pant vigour. Rhizobia inoculated plots recorded highly vigorous crops than un-inoculated crops. Fertilization of soybean with P and K significantly increased plant vigour over the control. The pots that were treated.

With P either at lower or higher dose resulted in significantly vigorous soybean compared with other treatments for the cropping seasons (Table 2).

Table 2. Effects of cropping systems, rhizobia inoculation and P and K fertilization on stem girth, plant vigour and number of leaves per plant.

Treatments	Stem Girth (mm)		Plant Vigour		Number of branches 4WAP	
	2015	2016	2015	2016	2015	2016
Cropping System						
SB	5.34±0.22a	8.33±0.32a	2.74±0.19a	2.33±0.18a	4.25±0.21a	4.48±0.12a
M+B(A)	4.97±0.18b	5.95±0.23b	2.65±0.23a	2.15±0.19a	4.25±0.20a	4.24±0.12a
M+B(B)	4.87±0.21b	5.95±0.23b	2.95±0.23a	2.43±0.19a	4.16±0.24a	4.68±0.50a
Rhizobia						
With	6.14±0.10a	7.29±0.25a	1.65±0.10b	1.37±0.07b	5.02±0.16a	4.81±0.34a
With out	3.99±0.09b	6.19±0.24b	3.91±0.11a	3.25±0.12a	3.43±0.13b	4.13±0.09b
Fertilizers						
0	4.66±0.24b	5.88±0.35c	3.39±0.33a	2.44±0.25ab	4.22±0.29ab	4.07±0.17b
20K	4.77±0.33b	5.93±0.38bc	2.84±0.35abc	2.67±0.34a	4.11±0.32ab	4.24±0.15b
40K	5.32±0.34a	6.78±0.43abc	3.03±0.33ab	2.83±0.28a	3.93±0.31b	4.26±0.15b
26P	5.02±0.32ab	6.82±0.46abc	2.53±0.35bc	1.94±0.26c	4.78±0.28a	5.69±1.14a
52P	5.29±0.32a	7.64±0.47a	2.60±0.32bc	1.94±0.29c	4.67±0.31a	4.22±0.15b
20K+26P	5.26±0.30a	7.17±0.55a	3.19±0.27a	2.17±0.26bc	3.96±0.38b	4.41±0.25b
40K+52P	5.12±0.36ab	6.96±0.59ab	2.89±0.37abc	2.14±0.29bc	3.89±0.38b	4.39±0.16b
3-Way ANOVA (F-statistics)						
CroSyt	5.045**	32.32***	1.678 ns	1.53ns	0.12ns	0.57ns
Rhiz	285.998***	15.63***	271.659*	210.37***	72.58***	4.01*
Fert	2.403*	2.99**	2.533***	4.17***	2.15*	1.48*
CroSyt*Rhiz	2.180 ns	0.28ns	0.892 ns	0.71ns	0.47ns	1.40ns
CroSyt*Fert	0.776 ns	0.54ns	1.159 ns	0.75ns	1.95*	0.66ns
Rhiz*Fert	1.101 ns	0.73ns	2.110 ns	0.32ns	2.39*	1.42ns
CroSyt*Rhiz*Fert	1.860ns	1.19ns	1.080 ns	0.97ns	1.26ns	1.39ns

Cro Syt: Cropping Systems; Fert: Fertilizers; Rhiz: Rhizobium; SB: Sole soybean; M+B (A): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 20 cm, maize and soybean respectively; M+B (B): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 40 cm, maize and soybean respectively; Values presented are means ± SE; *,**, ***: significant at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ respectively, ns = not significant, SE = standard error. Means followed by dissimilar letter(s) in a column are significantly different from each other at p=0.05 according to Fischer least significance difference (LSD). Note: plant vigour was assessed in a scale of 1-5. 1=Good; 5= Bad.

Number of branches per plant

The results of this study showed that Rhizobia inoculation significantly increased number of soybean leaves per plant over un-inoculated treatments. The rhizobia inoculated soybean produced mean leaf number of 5.02±0.16 and 4.81±0.34 compared with un-inoculated treatments which produced 3.43±0.13 and 4.13±0.09 for the 2015 and 2016 cropping season respectively. P and K fertilization also significantly increased the number of soybean leaves over the control for both two cropping seasons. The highest number of leaves was recorded in plots treated with 26 kg of P per hectare for the two cropping seasons.

Interactive effects of cropping systems, rhizobia inoculation and fertilizers on number of branches per plant for 2015 cropping season

For the 2015 cropping season, there were significant interactions between i) cropping systems and fertilizers and ii) Rhizobia inoculation and fertilizers on the number of branches per plant (Table 2; Fig. 4 and 5). Number of branches was higher in mono cropped soybean compared with intercropped one (Fig. 4). Fertilizer application also significantly increased the number of branches per plant over the control (Fig. 4). Rhizobia inoculation and fertilization with P and K also increased the number of branches per plant over the control (Fig. 5).

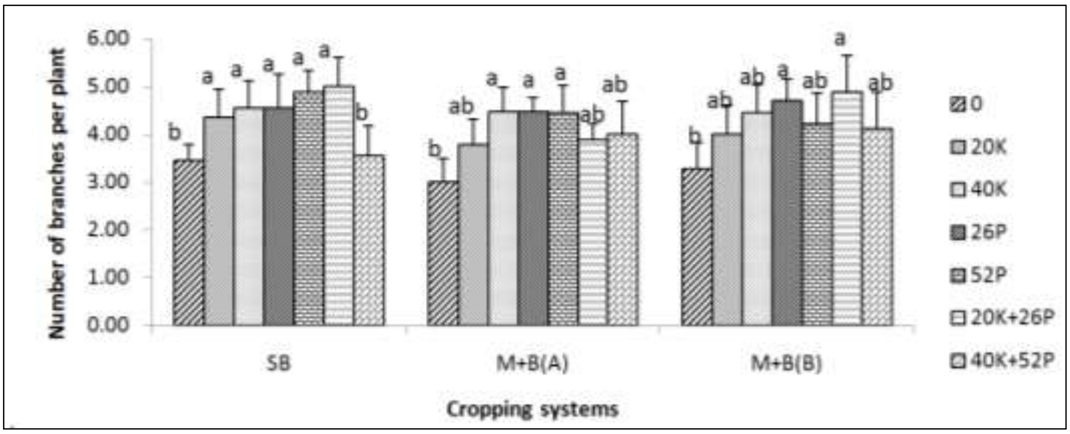

Fig. 4. Interactive effects of cropping systems and fertilizers on number of branches per plant for 2015 cropping season.

SB: Sole soybean; M+B (A): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 20 cm, maize and soybean respectively; M+B(B): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 40 cm, maize and soybean respectively. Bars followed by similar letter(s) are not significantly different from each other.

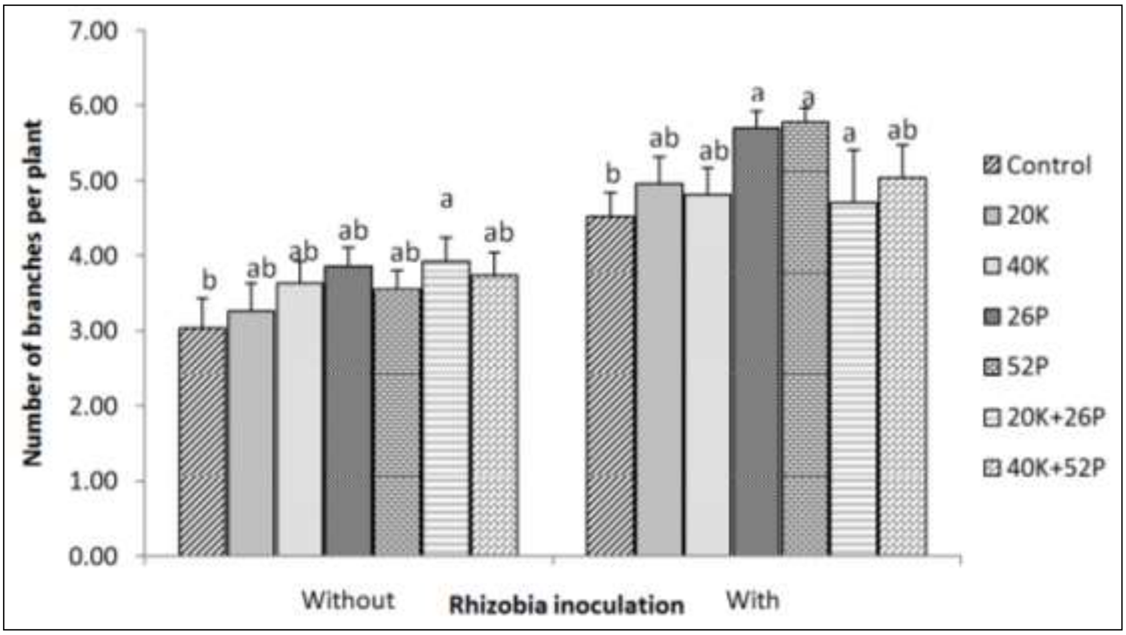

Fig. 5. Interactive effects of Rhizobia and fertilizers on number of braches per plant for 2015 cropping season.
SB: Sole soybean; M+B (A): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 20 cm, maize and soybean respectively; M+B(B): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 40 cm, maize and soybean respectively. Bars followed by similar letter(s) are not significantly different from each other.

Number of leaves per plant

The results presented in Table 3 indicated that for the 2015 cropping season, intercropped soybean produced many leaves measured at 2 weeks after planting (2 WAP) over the sole cropped soybean. The number of leaves counted at 4 weeks after planting (4 WAP) showed that cropping systems had no significant effect for the two cropping seasons (Table 3).

Rhizobia inoculation significantly increased the number of leaves compared with un-inoculated soybean for the two cropping seasons (Table 3).

Furthermore, fertilization of soybean with P and K significantly increased the number of leaves counted at 2 WAP and 4 WAP over the control for the two cropping seasons (Table 3).

Table 3. Effects of cropping systems, Rhizobia inoculation and fertilizer levels on number of leaves per plant and leaf area of soybean.

Cropping System	Number of Leaves 2WAP		Number of leaves 4WAP		LA	
	2015	2016	2015	2016	2015	2016
SB	5.09±0.06b	6.02±0.09a	8.54±0.29a	14.33±0.41a	221.39±11.18b	263.73±11.92a
M+B(A)	5.25±0.05a	6.06±0.15a	8.62±0.27a	14.37±0.48a	253.10±13.47a	283.95±13.86a
M+B(B)	5.28±0.07a	6.18±0.16a	8.87±0.31a	14.26±0.48a	236.90±14.66ab	292.55±12.03a
Rhizobia						
With	5.40±0.05a	6.41±0.12a	9.94±0.21a	16.12±0.33a	304.61±7.41a	307.23±9.95a
With out	5.02±0.046b	5.77±0.09b	7.41±0.12b	12.52±0.25b	169.65±5.78b	252.92±9.65b
Fertilizers						
0	5.00±0.11c	5.70±0.14b	7.28±0.25c	11.80±0.44d	177.45±16.41d	241.01±23.36c
20K	5.15±0.10bc	5.81±0.11b	8.31±0.35b	12.72±0.46cd	214.35±19.53c	282.69±17.63ab
40K	5.20±0.07abc	5.70±0.17b	8.22±0.38b	13.28±0.48c	227.85±18.78bc	249.14±18.50bc
26P	5.39±0.09a	6.41±0.26a	9.37±0.46a	14.70±0.55b	244.28±19.60ab	293.21±20.81ab
52P	5.26±0.08ab	6.48±0.25a	9.26±0.49a	15.41±0.66ab	257.65±21.04a	294.86±19.19ab
20K+26P	5.31±0.08ab	6.37±0.19a	9.34±0.44a	16.39±0.75a	268.21±20.57a	303.13±15.63a
40K+52P	5.13±0.11bc	6.15±0.23ab	8.96±0.46ab	15.93±0.72a	270.13±18.86a	296.50±17.18ab
3-Way ANOVA F-statistics						
CroSyt	3.98*	0.47ns	0.97ns	0.04ns	6.15**	1.51ns
Rhiz	40.19***	20.60***	153.23***	132.38***	334.21***	15.28***
Fert	2.63*	3.46**	8.28***	17.72***	11.70 ***	1.82*
CroSyt*Rhiz	4.07*	2.37ns	2.55ns	2.43ns	3.09ns	1.50ns
CroSyt*Fert	0.58ns	0.52ns	0.55ns	0.69ns	1.10ns	0.66ns
Rhiz*Fert	0.36ns	1.15ns	1.24ns	0.74ns	1.05ns	0.76ns
CroSyt*Rhiz*Fert	1.36ns	1.13ns	1.26ns	0.89ns	0.74ns	0.84ns

Cro Syt: Cropping Systems; Fert: Fertilizers; Rhiz: Rhizobium; SB: Sole soybean; M+B (A): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 20 cm, maize and soybean respectively; M+B (B): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 40 cm, maize and soybean respectively; Values presented are means ± SE; *,**, ***: significant at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ respectively, ns = not significant, SE = standard error. Means followed by dissimilar letter(s) in a column are significantly different from each other at p=0.05 according to Fischer least significance difference (LSD).

Leaf Area

All the treatments applied in this experiment had statistical effect on the leaf area of soybean measured at 50% pod formation. The results presented in Table 3 showed that sole soybean had smaller leaves measured in terms of leaf area compared with the intercropped soybean which gave significantly higher leaf area for the 2015 cropping season.

In the second cropping season, the cropping systems did not significantly increase leaf area. However, numerically leaf areas of soybean were higher in intercropped plots compared with sole crops (Table 3). Rhizobia inoculated soybean significantly increased leaf areas relative to un-inoculated soybean for the two cropping seasons.

It was also observed that fertilization of soybean with P and K significantly increased the leaf areas over the control. The combined P and K applied at their lower rate significantly gave higher values of leaf areas compared with all other treatments for the two cropping seasons.

Interactive effects of cropping systems and Rhizobia on number of leaves counted 2 weeks after planting for 2015 cropping season

Significant interactions between cropping systems and Rhizobia inoculation on number of leaves per plant were observed in this study. Soybean grown alone had more number of leaves compared with intercropped soybean. Similarly, Rhizobia inoculated soybean had more number of leaves compared with un-inoculated soybean (Fig. 6).

Discussion

From this study, analysis of variance showed that all treatments had significant effects on almost all parameters measured. Supplying soybean with *Rhizobium* inoculants significantly increased growth parameters of soybean. Specifically, Rhizobia inoculation significantly increased plant height, stem girth, number of branches per plant, number of leaves per plant and soybean plant vigour over un-inoculated treatments. Similar to this study, other related studies have reported the increase in growth parameters of leguminous plant following Rhizobia inoculation (Raj *et al.*, 2003; Pirlak and Kose 2009; Wu *et al.*, 2013; Nyoki and Ndakidemi, 2014a; Fageria *et al.*, 2014; Bai *et al.*, 2016). The increased growth parameters of soybean might have been attributed by rhizobia inoculation which facilitates plant growth through: addition of nitrogen through biological nitrogen fixation and decomposition of plant residuals (Wagner, 2011); production of plant growth hormone (Yasmeen and Bano, 2014); increases surface area for nutrients uptake; or control diseases by inhibiting colonization of plant roots from phytopathogens (Wall *et al.*, 2000; Doornbos, *et al.*, 2012; Verma *et al.*, 2012).

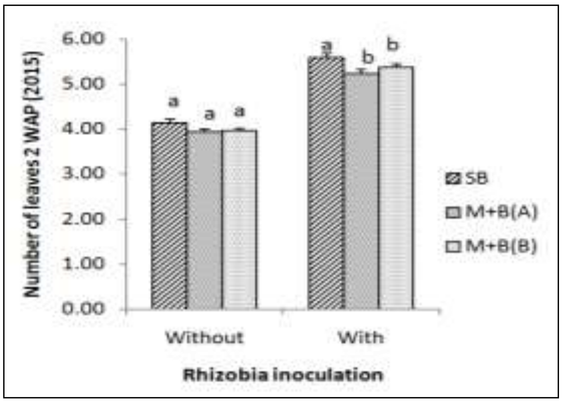

Fig. 6. Interactive effects of cropping systems and Rhizobia on number of leaves counted 2 weeks after planting for 2015 cropping season.

SB: Sole soybean; M+B (A): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 20 cm, maize and soybean respectively; M+B(B): Maize/soybean intercropped at a spacing of 75 x 60 cm and 75 x 40 cm, maize and soybean respectively. WAP = Weeks after planting. Bars followed by similar letter are not significantly different from each other.

Similarly, cropping systems and fertilization of soybean with P and K significantly increased some growth parameters of soybean. For example, for the two cropping seasons, cropping systems had significant effects on plant height and stem girth. The plant height measured 2 WAP had no significant different from each treatment for first cropping season. This could be due to the fact that both crops were of the same height hence there was no completion for light.

Plant heights measured at 4 and 6 WAP significantly differed from each cropping system, where the soybeans were significantly taller in intercropped plots compared with mono cropped soybean. Similar to our findings, Hamd Alla, *et al.* (2014) reported the increased cowpea height in intercropping relative to mono cropped cowpea. Furthermore, Hirpa (2014) reported that there was an increase in height of Haricot bean intercropped with maize compared with sole grown Haricot bean. The increased plant height in intercropping over sole crop may be due to the effect of shading from maize which normally grows taller and faster than soybean (Hamd Alla *et al.* 2014) and below ground interactions of intercropped plant (Ndakidemi, 2006). Therefore, in the struggle for accessing sunlight, the intercropped soybean becomes taller than those in mono cropped plots. Similarly, other researchers have reported the increased legume plant height in intercropping compared with sole crop (Megawer *et al.*, 2010; Soleymani and Mohammad, 2012) and reduced number of leaves per plant in intercropping relative to sole crop (Maluleke *et al.*, 2005). Furthermore, the findings of this study showed that the stem girths were increased in plots where soybeans were grown as mono crop relative to those under intercropping. The possible explanation for this could be due to reduced completion for growth resources in mono cropped soybean relative to those under intercropping.

P and K fertilization significantly improved growth parameters of such as plant height, stem girth, number of branches per plant, number of leaves per plant and soybean plant vigour over the control treatment. It is well known that plants require nutrients for proper growth. From the current study, we found that P and K fertilizers whether applied singly or combined, at lower rates or doubled significantly increased growth parameters of soybean relative to the control. Generally, almost all growth parameters of soybean were greatly improved in plots received 26 P, 52 P and 20 K + 26 P kg ha^{-1} relative to other treatments.

The current study showed significant interactions between main plot treatments and sub plot treatments on some growth parameters of soybean. Interaction of treatments were observed in plant height measured at different growth stages and at different cropping seasons, number of branches per plant for first cropping season, and number of leaves per plant. Regardless of the growth stage and cropping season from which the parameter was measured, existence of significant interactions means that both treatments have better contributed to the performance of specific parameter. This argument is supported by Bambara and Ndakidemi, (2010) who observed the presence significant interaction between *Rhuzobium*, molybdenum and lime on yield attributes of *P. vulgaris*. In this study, there were significant interactions between 1. Rhizobia and cropping systems on plant height measured 2 and 4 WAP in 2016 cropping season; 2. Rhizobia and cropping systems on plant height measured at 6 WAP in 2015 cropping season; 3. Rhizobia and fertilizers on plant height measured at 6 WAP in 2015 cropping season; 4. Rhizobia, cropping systems and fertilizers on plant height measured at 6 WAP in 2015 cropping season. 5. Cropping systems and fertilizers on number of branches in 2015 cropping season 6. Rhizobia inoculation and fertilizers on number of branches per plant counted in 2015 cropping season and 7. Rhizobia and cropping systems on number of leaves per plant counted 2 WAP in 2015 cropping season. Similar to the current study, Onduru *et al.* (2008) reported the steady vigorous growth of cowpeas in the treatment, *Rhizobium* and TSP postulating that it could be due to interactive effects of Rhizobium and TSP.

Conclusion

According to the data of the current study, significant differences have been observed among the treatments of the main plots, sub plots and the sub-sub plots. The data showed that cropping systems influenced plant height whereas intercropped soybeans were taller compared with mono cropped one. The stem girths of soybean were bigger in pure stand soybean than in intercrop. *Rhizobium* inoculation significantly increased the plant height, stem girth, number of leaves and number of branches per plant, leaf area and finally plant vigour over un-inoculated treatments. P and K fertilization also significantly improved growth parameters of soybean that were assessed. However, each parameter was affected differently from each other with the level and type of fertilizer applied (Table 1, 2 and 3). Our general observation is that fertilizer levels of 26 P, 52 P and 20 K + 26 P kg ha^{-1} performed better in terms of improving growth parameters of soybean which eventually improves yield. Significant interactions were reported by inoculating the soybean with *Rhizobium*, and supplying P and K, in intercropping systems indicating the need for these inputs combination in the study area.

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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