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Yield responses of bush bean varieties to different planting densities and rates of phosphorous fertilizer

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Common bean is commonly grown by smallholder farmers under quite diverse farming systems and it is for both food security and income generation. The impact of plant density is important to bean growers for yield optimization and the inadequate source of phosphorus leads to low productivity due to its significant in growth and development. This study focused on determining optimal spacing of different bush bean varieties for enhancing productivity in relation to application rates of P-fertilizers. A field experiment was conducted at Selian Agricultural Research Institute during short and long rain cropping seasons of 2016/2017 and 2017/2018 respectively. Treatments comprised of three bush bean varieties (Lyamungu 90, JESCA and KATB1), three spacing options 50 cm x 20 cm; 40 cm x 20 cm and 30 cm x 20 cm and four levels of P-fertilizers of 0 kg ha^{-1}; 20 kg ha^{-1}; 40 kg ha^{-1} and 60 kg ha^{-1} replicated three times in randomized complete block factorial design. Both treatments and their interaction showed significant differences ($p \leq 0.05$). The combination for spacing of 30 cm x 20 cm with planting density of 333,333 plants ha^{-1} and P-fertilizer rate of 60 kg ha^{-1} with productivity of 2580 kg ha^{-1} enhanced bean productivity compared to commonly used combinations with productivity of < 600 kg ha^{-1}.

Key words: Productivity, interactions, food security, plant density and yield responses.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is the leading leguminous crop, accounting for 78% of land under legumes in Tanzania (FAO, 2013). Annual consumption of beans in the world is as high as 66 kg per person (Grisley, 1990; Petry et al., 2015), while in Tanzania per capita bean consumption is 19.3 kg per person, contributing 16.9% protein and 7.3% calories in human nutrition and 71% of leguminous protein in diets

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(Rugambisa, 1990; Grisley, 1990; Katungi et al., 2009).

It is estimated that over 75% of rural households in Tanzania depend on beans for daily subsistence (Xavery et al., 2006; Kalyebara et al., 2008; Binagwa et al., 2018). The crop is grown by smallholder farmers under quite diverse farming systems and agro-climatic conditions; both for household food requirements and income generation (Allen et al., 1989; Allen and Edje, 1990; Musimu, 2018). Average bean yields in Tanzania are around 500 kg ha^{-1} although the potential yield under reliable rain-fed conditions is 1500–3000 kg ha^{-1}, using improved bean varieties accompanied with good agricultural practices. The main reasons for the low yield obtained by most smallholders are; low soil fertility, inadequate use of improved bean varieties, poor crop managements and susceptibility to insect pests and diseases (Hillocks et al., 2006 and Saimon et al., 2016).

Under current management practices in Tanzania, beans are planted at a spacing of 50 cm between rows and 20 cm between planting hills, while maintaining two seeds per hill which results to 200,000 plants per ha (Kanyeka et al., 2007) without applying P-fertilizers. The impact of plant density on dry bean production is important to bean growers for optimizing yield. However, higher planting density will require higher application rates of fertilizers to compensate crop demands depending on the availability of such nutrients in the soil, hence the need to determine optimal spacing for planting high yielding with good market and culinary characteristics in relation to P-fertilizer application rates by considering the actual situation prevailing under local farmers conditions – little/no fertilizer use and financial constrain.

Loss of soil fertility may result from excessive nutrient mining through crop harvests, burning, leaching of nutrients, volatilization and de-nitrification (FAO, 2004; Drechsel et al., 2015), with no adequate nutrient replenishment particularly in areas where high yielding bean varieties are adopted by farmers (Stoorvogel et al., 1993). Most farmers in the northern zone are not using fertilizers on bean, hence low yield under farmers' condition. Mineral fertilizers may also be required to meet the crop nutrient requirement for optimum crop production (Breman, 1990; Drechsel et al., 2015) and in African region; farmlands are lost due to their poor management, causing average annual losses of topsoil in N, P and K at 22, 2.5 and 15 kg ha^{-1} respectively.

Therefore, for better management of land resources, it is imperative to measure the initial soil fertility for its ability to provide essential nutrients for crop growth and development (Stoorvogel et al., 1993). Mineral fertilizers play important role in restoring soil fertility status. The purpose of this study was; i) to assess the effects of different planting densities for better yield of the bush bean varieties ii) evaluate the effects of different levels of phosphorous fertilizer on productivity of the bush bean varieties and iii) determine the interaction effects of different planting densities and levels of phosphorous fertilizer on productivity of the bush bean varieties.

MATERIALS AND METHODS

Description of the study site

The experiment was conducted at Selian Agricultural Research Institute (ARI-Selian) experimental site during the short rain cropping season of 2016/2017 and the long rain cropping season of 2017/2018. ARI-Selian is located at Arumeru district (Arusha region) in northern Tanzania which lies at 10° 22' S latitude and 40° 10' E longitude with an altitude of 1378 m above sea level with mean annual temperature and rainfall of 19.2°C and 1103 mm respectively.

Soil types and its physical-chemical characteristics

The experimental site had the textural class of silty loam based on USDA textural class triangle (Brady and Weil, 2002) with pH value of 5.6, rated as medium acid, suitable for cultivation of most crops including bean (Landon, 1991). The soil has very low organic carbon (0.53%) corresponding to very low organic matter (0.92%), total nitrogen (0.079%), exchangeable potassium (0.17 cmol (+)/kg) and medium available phosphorous (8.0 mg/kg); this classify that, the soil fertility status is medium fertility which is moderately suitable for bean cultivation.

Land preparation, treatments and experimental design

Land preparation was carried out by ploughing by tractor followed by harrowing. Treatments comprised of three bush bean varieties Lyamungu 90, JESCA and KATB1 sourced from SARI bean section; three plant densities of 200,000; 250,000 and 333,333 plants ha^{-1} maintained at a spacing of 50 cm x 20 cm, 40 cm x 20 cm and 30 cm x 20 cm respectively and four levels 0, 20, 40 and 60 kg ha^{-1} of di-ammonium sulphate (DAP) fertilizer as a source of phosphorous (applied prior to bean planting). The treatments were laid out in a randomized completely block design (RCBD) in a 3 x 3 x 4 factorial arrangement with three replications. The size of each experimental plot was 1.2 m x 3 m (3.6 m^2) and two seeds were planted per hole.

Other agronomic management practices including insect pest control and weeding were executed uniformly as recommended by Kanyeka et al. (2007) and national bean research program for bean production in Tanzania.

Yield and yield components data

At harvesting stage (12 weeks after planting), five plants randomly selected from the net harvesting area of 3.0, 2.4 and 2.7 m^2 for 200,000, 250,000 and 333,333 planting densities respectively, were used for assessing the number of pods per plant and number of seeds per pod, while the biomass and grain yields were estimated from the plants within the entire net harvesting area. Number of pods was determined by detaching and counting the total number of pods from the collected parent plants of each plot while number of seeds was determined by counting the total seeds in each pod from the sampled plants per plot. The above ground biomass yield was determined by weighing the straw collected from each plot using weighing balance and the obtained weight was converted to kg ha^{-1}. Grain yield per plot was determined by weighing the grain harvested per plot using sensitive weighing balance and the obtained weight was converted to kg ha^{-1} after adjustment at 13% moisture content by using moisture tester.

Statistical data analysis

The data on the number of pods per plants, seeds per pod, biomass and grain yields collected were subjected to a combined analysis of variance (ANOVA) using Genstat (15th Edition) statistical software. Significant treatment means were separated by Duncan multiple range test (DMRT) at 5% level of probability.

RESULTS AND DISCUSSION

Yield performance of three bush bean varieties

There was significant difference ($p \leq 0.05$) among the three bush bean varieties with respect to number of pods per plant, number of seeds per pod, biomass and grain yields as illustrated in Table 1. Results showed that higher number of pods per plant (7.89) was observed in KAT-B1 variety followed by JESCA variety (6.96) with the least number of pods per plant (6.71) observed in Lyamungu 90 variety as shown in Table 1. Results from the study showed no significant differences ($p \leq 0.05$) between JESCA and KAT-B1 varieties with respect to number of seeds per pod while the lowest number of seeds per pod of 3.82 was given by Lyamungu 90 variety.

The highest biomass yields of 2767 kg ha^{-1} was obtained in KAT-B1 variety while Lyamungu 90 and JESCA varieties did not show significant differences ($p \leq 0.05$) with respect to biomass yields. JESCA variety resulted higher grain yields of 1715 kg ha-1 followed by Lyamungu 90 variety (1441 kg ha-1) with the least grain yield of 1344 kg ha-1 in KAT-B1 variety as presented in Table 1. The trends of significant differences ($p \leq 0.05$) observed among the bush bean varieties in terms of yields and yield components may be ascribed to the differences in maturing characteristics among the tested varieties; JESCA and KAT-B1 being early maturing varieties while Lyamungu 90 variety being a late maturing variety. The findings of this study agree with the results of Eftekhar et al. (2012) who reported significant effects of different white bean cultivars on number of grains per plant and grain yields.

Effects of planting density on number of pods per plant, number of seeds per pod, biomass and grain yields of the three bush bean varieties

There were no significant differences ($p \leq 0.05$) among the three planting densities (200,000, 250,000 and 333, 333 plants ha^{-1}) with respect to number of pods per plant and number of seeds per pod as shown in Table 2. This study is contrary with the results of Eftekhar et al. (2012) who reported significant effect of planting density on number of pods per plant of white bean cultivars.

Results revealed that the three planting densities significantly ($p \leq 0.05$) influenced increase in biomass and grain yields as illustrated in Table 2. Results also showed no significant difference ($p \leq 0.05$) between the plant densities of 250,000 and 333,333 plants ha^{-1} in terms of in biomass and grain yields, however, these two planting densities gave the highest biomass and grain yields. The planting density of 200,000 plants ha^{-1} gave lowest biomass and grain yields. The results support the findings of Eftekhar et al. (2012) who reported significant effect of planting density on biological and grain yield of white bean cultivars.

Similarly, the results of this study are in line with the findings by Moniruzzaman et al. (2009) who observed higher pod yield of French bush bean varieties in the highest plant density and the lowest pod yield with the lowest plant density. However, the study contradicts the findings of Hang et al. (1993) who reported no significant effects of grains per pods of adzuki beans and dry beans due to planting density.

Effects of different rates of phosphorous fertilizer on number of pods per plant, number of seeds per pod, biomass and grain yields of the three bush bean varieties

Results from the study show that there were significant differences ($p \leq 0.05$) among the four rates of phosphorus fertilizer with respect to number of pods per plant except for number of seeds per pod, biomass and grain yields as shown in Table 2. The highest number of pods per plants of 7.944 was obtained when phosphorous fertilizer was applied at a rate of 60 kg ha^{-1}. However, the results show no significant differences ($p \leq 0.05$) with respect to number of pods per plant when phosphorous fertilizer at a rate of 0 and 40 kg ha^{-1} was applied as presented in Table 2. The results of this study contradict the findings of Nkaa et al. (2014) who reported significant increase in biomass yields and seed yields of cowpea varieties due to application of phosphorous fertilizer at different rates in comparison to the control.

Effects of the interaction of bush bean varieties and plant densities on number of pods per plant, number of seeds per pod, biomass and grain yields

Number of pods per plant, number of seeds per pod, biomass and grain yields was significantly different ($p \leq 0.05$) influenced by the interaction of bush bean varieties and planting densities as shown in Table 3. The maximum number of pods per plant of 8.52 was obtained in KAT-B1 variety by planting density of 250,000 plants ha^{-1}. The results show that the interaction of Lyamungu 90 variety by planting density of 250,000 plants ha^{-1},

Table1. Performance three bush bean varieties on number of pods per plant, number of seeds per pod, biomass and grain yields.

Treatment (variety)	No. of pod/plant	Seed/pod	Biomass (kg ha^{-1})	Grain yields (kg ha^{-1})
Lyamungu 90	6.71^{a}	3.82^{a}	2044^{a}	1441^{ab}
JESCA	6.96^{ab}	4.39^{b}	1936^{a}	1715^{b}
KAT-B1	7.89^{b}	4.14^{b}	2767^{b}	1344^{a}
CV (%)	40.4	22.5	85.0	59.0

Means on with the same letter on the column indicates no significant difference (p ≤0.05) between the treatments using Duncan Multiple Range Test (DMRT).

Table 2. Effects of planting density and phosphorus on number of pods per plant, number of seeds per pod, biomass and grain yields.

Treatment		No. of pod/plant	Seed/pod	Biomass (kg/ha)	Grain yields (kg/ha)
Plant density (plants ha^{-1})	200,000 (50cm x 20cm)	7.161^{a}	4.178^{a}	1341^{a}	878^{a}
	250,000 (40cm x 20cm)	7.617^{a}	4.072^{a}	2613^{b}	1698^{b}
	333,333 (30cm x 20cm)	6.781^{a}	4.099^{a}	2792^{b}	1923^{b}
Phosphorous rate (kg ha^{-1})	60	7.944^{b}	4.163^{a}	2674^{a}	1582^{a}
	40	7.256^{ab}	3.974^{a}	2136^{a}	1471^{a}
	20	6.622^{a}	4.180^{a}	2197^{a}	1510^{a}
	0	6.922^{ab}	4.148^{a}	1988^{a}	1435^{a}
CV (%)		40.4	22.5	85.0	59.0

Means on with the same letter on the column indicates no significant difference (p ≤0.05) between the treatments using Duncan Multiple Range Test (DMRT).

Table 3. The interaction effects of bush bean varieties and planting density on number of pods per plant, number of seeds per pod, biomass and grain yields.

Treatment (variety x plant density)	No. of pod/plant	Seed/pod	Biomass (kg/ha)	Grain yields (kg/ha)
V1S1	7.10^{ab}	3.76^{a}	1428^{ab}	853^{a}
V1S2	6.75^{ab}	3.75^{a}	1977^{abc}	1510^{bc}
V1S3	6.28^{a}	3.94^{ab}	2725^{cd}	1958^{c}
V2S1	6.50^{a}	4.43^{b}	1112^{a}	1058^{ab}
V2S2	7.58^{ab}	4.50^{b}	2082^{abc}	2017^{c}
V2S3	6.79^{ab}	4.23^{ab}	2614^{bcd}	2069^{c}
V3S1	7.88^{ab}	4.34^{ab}	1483^{ab}	724^{a}
V3S2	8.52^{b}	3.97^{ab}	3781^{d}	1566^{bc}
V3S3	7.28^{ab}	4.13^{ab}	3037^{cd}	1744^{c}
CV (%)	40.4	22.5	85.0	59.0

Means on with the same letter on the column indicates no significant difference (p ≤0.05) between the treatments using Duncan multiple range test (DMRT). Varieties: V1= Lyamungu 90, V2= JESCA and V3= KAT-B1, planting density: S1=200,000 plants ha^{-1}, S2=250,000 plants ha^{-1}, S3= 333,333 plants ha^{-1}, phosphorous rates: P1= 60 kg ha^{-1}, P2= 40 kg ha^{-1}, P3= 20 kg ha^{-1} and P4= 0 kg ha^{-1}.

JESCA variety by planting density of 250,000 and 333,333 plants ha^{-1}, KAT-B1 variety by planting density of 200,000 and 333,333 plants ha^{-1} did not significantly ($p \leq 0.05$) influence increase in the number of pods per plant as shown in Table 3. Similarly, the results show no significant differences ($p \leq 0.05$) between Lyamungu 90 variety by planting density of 333,333 plants ha^{-1} and JESCA variety by planting density of 200,000 plants ha^{-1}

in terms of number of pods per plant; however, these treatments gave the lowest number of pods per plants as compared to other treatment combinations as shown in Table 3.

Results showed no significant differences ($p \leq 0.05$) between JESCA variety by planting density of 250,000 and 200,000 plants ha^{-1} respectively, in terms of number of seeds per pod; however, these treatments gave higher number of seeds per pod as compared to other treatment combinations. Similarly, Lyamungu 90 variety by planting density of 333,333 plants ha^{-1}, JESCA variety by planting density of 333,333 plants ha^{-1}, KAT-B1 variety by planting density of 250,000 and 333,333 plants ha^{-1} did not show significant differences ($p \leq 0.05$) with respect to number of seeds per pod. The lowest number of seeds per pod was obtained in Lyamungu 90 variety by planting density of 333,333 plants ha^{-1} and JESCA variety by planting density of 200,000 plants ha^{-1}, these treatments, however, did not show significant differences ($p \leq 0.05$) among themselves in terms of number of seeds per pod.

The highest biomass yields of 3781 kg ha^{-1} was obtained from KAT-B1 variety by planting density of 250,000 plants ha^{-1} followed by KAT-B1 variety by planting density of 333,333 plants ha^{-1} and Lyamungu 90 variety by planting density of 333,333 plants ha^{-1} which did not differ significantly ($p \leq 0.05$) among themselves in terms of biomass yields as shown in Table 3. Results also indicate that JESCA variety by planting density of 250,000 plants ha^{-1} statistically gave similar biomass yields followed by treatment KAT-B1 and Lyamungu 90 varieties by planting density of 200,000 plants ha^{-1} with the least biomass yields of 1112 kg/ha recorded in the JESCA variety by planting density of 200,000 plants ha^{-1}.

Results indicated that Lyamungu 90 variety by planting density of 333,333 plants ha^{-1}, JESCA variety by planting density of 250,000 and 333,333 plants ha^{-1} and KAT-B1 variety by planting density of 333,333 plants ha^{-1} did not show significant differences ($p \leq 0.05$) among themselves; however they gave higher grain yields as compared to other treatment combinations. Similarly, Lyamungu 90 and KAT-B1 varieties by planting density of 200,000 plants ha^{-1} did not show significant differences ($p \leq 0.05$) between themselves and gave the lowest grain yields as compared to other treatment combinations as shown in Table 3.

The findings of significant increase in number of pods per plant, number of seeds per pod, biomass and grain yields was significantly ($p \leq 0.05$) due to the interaction of bush bean varieties and planting densities are in agreement with the results of Eftekhar et al. (2012) who also reported that the interaction between white bean cultivars and plant density was significant on number of branches, number of pods per plant, biological yield and grain yield. However, the findings of this study contradict the results of Pawar et al. (2007) who reported insignificant increase in yield components and grain yields of French bean due the interaction effect between the varieties and plant density.

Effects of the interaction of bush bean varieties and rates of phosphorous fertilizer on number of pods per plant, number of seeds per pod, biomass and grain yields

Results on the effects of the interaction of variety and rates of phosphorous fertilizer on yield attributes of bush bean varieties are presented in Table 4. Number of pods per plant, number of seeds per pod, biomass and grain yields were significantly ($p \leq 0.05$) influenced by the interaction of bush bean varieties and phosphorus fertilizer as presented in Table 4. Similarly, Chekanai et al. (2018) found that common bean dry biomass was significantly increased by application of N, P and NP in both degraded and non-degraded soils. On the other hand, Magelanga (2013) found significant effects of P application on yield and yield components on bean lines. Magelanga (2013) found that; plants grown without P fertilizer had the lowest pod yield and pod number caused by failure of fertilization due to production of non-viable pollen grains. Fageria et al. (2010) reported that, the contribution of yield components in increasing grain yield was in the order of number of pods per plant > seeds per pod > 100 grain weight. Similarly, Fageria and Santos (2008) observed that, number of grain per pod and weight of hundred grains are important yield components. Further, it has been documented that grain yield in beans as affected by the above mentioned seed yield components is usually affected by available P to the crop. Studies conducted by Hussain (1983) showed that application of P to legumes would improve seed yield considerably. Thus, any reduction in these yield components directly affects overall grain production. The reduction in yield is largely due to reduction in number of pods per plant as reported by Lopez et al. (1990). The maximum number of pods per plant of 8.41 was obtained from KAT-B1 variety was planted with phosphorous fertilizer at a rate of 60 kg ha^{-1}. Results indicate that all other treatment combinations did not show significant differences ($p \leq 0.05$) among themselves except when JESCA variety was planted with phosphorous fertilizer at a rate of 20 kg ha^{-1} treatment that gave the lowest number of pods per plant. The highest number of seeds per pod of 4.64 was recorded when JESCA variety was planted with phosphorous fertilizer at a rate of 20 kg ha^{-1} as compared to other treatments with the least number of pods per plant of 3.63 which was obtained from Lyamungu 90 variety, and was planted with phosphorous fertilizer at a rate of 60 kg ha^{-1}.

The highest biomass yields of 3586 kg ha^{-1} was obtained when KAT-B1 variety was planted with phosphorous fertilizer at a rate of 60 kg ha^{-1}; followed by Lyamungu 90 variety which was planted with phosphorous fertilizer at a rate of 20 kg ha^{-1}; JESCA

Table 4. The interaction effects of bush bean varieties and rates of phosphorus on number of pods per plant, number of seeds per pod, biomass and grain yields.

Treatment (variety x phosphorous)	No. of pod/plant	Seed/pod	Biomass (kg/ha)	Grain yields (kg/ha)
V1P1	7.24[ab]	3.63[a]	2107[a]	1327[ab]
V1P2	6.42[ab]	3.67[ab]	2010[a]	1459[ab]
V1P3	6.22[ab]	3.86[abc]	2248[ab]	1494[ab]
V1P4	6.94[ab]	4.10[abcd]	1809[a]	1483[ab]
V2P1	8.18[ab]	4.41[cd]	2329[ab]	1991[b]
V2P2	7.26[ab]	4.36[bcd]	1876[a]	1768[ab]
V2P3	6.09[a]	4.64[d]	1917[a]	1700[ab]
V2P4	6.31[ab]	4.14[abcd]	1623[a]	1400[ab]
V3P1	8.41[b]	4.44[cd]	3586[b]	1430[ab]
V3P2	8.09[ab]	3.90[abc]	2523[ab]	1187[a]
V3P3	7.56[ab]	4.03[abcd]	2427[ab]	1337[ab]
V3P4	7.51[ab]	4.20[abcd]	2531[ab]	1424[ab]
CV (%)	40.4	22.5	85.0	59.0

Means on with the same letter on the column indicates no significant difference ($p \leq 0.05$) between the treatments using Duncan multiple range test (DMRT). Varieties: V1= Lyamungu 90, V2= JESCA, V3= KAT-B1, phosphorous rates: P1= 60 kg ha^{-1}, P2= 40 kg ha^{-1}, P3= 20 kg ha^{-1} and P4= 0 kg ha^{-1}.

variety JESCA variety was planted with phosphorous fertilizer at a rate of 60 kg ha^{-1}; and KAT-B1 variety was planted with phosphorous fertilizer at a rate of 40, 20 and 0 kg ha^{-1}. These, however, did not significantly ($p \leq 0.05$) differ among themselves in terms of biomass yields with the lowest biomass yields obtained from the Lyamungu 90 variety which was planted with phosphorous fertilizer at a rate of 60 and 40 kg ha^{-1}, and JESCA variety which was planted with phosphorous fertilizer at a rate of 40, 20 and 0 kg ha-1.

Results show no significant differences ($p \leq 0.05$) among Lyamungu 90 variety which was planted with phosphorous fertilizer at a rate of 60, 40, 20 and 0 kg ha-1; JESCA variety which was planted with phosphorous fertilizer at a rate of 40, 20 and 0 kg ha^{-1}; and KAT-B1 variety which was planted with phosphorous fertilizer at a rate of 40, 20 and 0 kg ha^{-1} in terms of grain yields; except for JESCA variety which was planted with phosphorous fertilizer at a rate of 60 kg ha^{-1} and that gave the highest grain yield of 1991 kg ha^{-1}.

The lowest grain yield of 1187 kg ha-1 was obtained from KAT-B1 variety which was planted with a phosphorous fertilizer at a rate of 40 kg ha^{-1} as presented in Table 4.

Effects of the interaction of planting densities and rates of phosphorus fertilizer on number of pods per plant, number of seeds per pod, biomass and grain yields of the three bush bean varieties

Results on the effects of the interaction of different planting densities and rates of phosphorous fertilizer on grain yields and yield components of bush bean varieties are presented in Table 5. There were significant ($p \leq 0.05$) differences in yields components (number of pods per plant, seeds per pod and biomass) and grain yields of bush bean varieties due to the interaction effect of planting density and rates of phosphorous fertilizer.

The maximum number of pods per plant of 10.267 was recorded when KAT-B1 variety was planted at the lowest planting density of 200,000 plants ha^{-1} and at a phosphorous rate of 40 kg ha^{-1} followed by JESCA variety when planted at a lowest planting density of 200,000 plants ha^{-1} and a phosphorous fertilizer at a highest rate of 60 kg ha^{-1}. The lowest number of pods per plant was recorded in JESCA variety when planted at a lowest planting density of 200,000 plants ha^{-1} and a phosphorous fertilizer at a rate of 0 and 20 kg ha^{-1} respectively. The decrease in number of pods per plant with increase in plant density could be due to increased intra specific competition which eventually caused reduction in number of pods per plant.

The findings support the results of Mulatu et al. (2017) who also reported that the interaction effect of plant density and level of phosphorous showed significant ($p \leq 0.05$) effect on number of pods per plant of haricot bean. Furthermore, the findings of the study contradict the results of Mulatu et al. (2017) who reported that the highest number pods per plant was recorded at the highest phosphorous level and the lowest plant population density, while the lowest number per plant recorded at the highest plant population density with the lowest phosphorous level which is not the case with the findings of the study. In agreement with this study, Abdel (2008) reported that faba bean developed more and vigorous leaves on low plant density, and helped to improve the photosynthetic efficiency of the crop and

Table 5. The interaction effects of bush bean varieties and rates of phosphorus fertilizer on number of pods per plant, number of seeds per pod, biomass and grain yields.

Treatment	No. of pod/plant			Seed/pod			Biomass (kg/ha)			Grain yields (kg/ha)		
Plant density x phosphorous	**V1**	**V2**	**V3**	**V1**	**V2**	**V3**	**V1**	**V2**	**V3**	**V1**	**V2**	**V3**
S1P1	6.87^{ab}	9.07^{ab}	8.03^{ab}	3.20^{a}	4.33^{abc}	4.53^{abc}	1183^{a}	1489^{a}	1522^{a}	544^{a}	1156^{abcdefgh}	667^{abc}
S1P2	7.57^{ab}	7.03^{ab}	10.27^{b}	3.60^{abc}	4.27^{abc}	4.30^{abc}	11111^{a}	944^{a}	1561^{a}	911^{abcdef}	1233^{abcdefgh}	789^{abcd}
S1P3	5.80^{a}	4.9^{a}	6.77^{ab}	4.17^{abc}	4.60^{bc}	4.37^{abc}	1728^{a}	1211^{a}	1531^{a}	900^{abcdef}	933^{abcdef}	806^{abcde}
S1P4	8.17^{ab}	4.93^{a}	6.47^{ab}	4.07^{abc}	4.53^{abc}	4.17^{abc}	1689^{a}	806^{a}	1317^{a}	1056^{abcdefgh}	911^{abcdef}	633^{ab}
S2P1	7.97^{ab}	7.77^{ab}	8.67^{ab}	3.90^{abc}	4.47^{abc}	4.37^{abc}	2069^{a}	2361^{a}	6076^{b}	1361^{abcdefghi}	2236^{ghi}	1833^{bcdefghi}
S2P2	6.17^{a}	7.70^{ab}	7.83^{ab}	3.33^{ab}	4.40^{abc}	3.37^{ab}	2479^{a}	1757^{a}	2736^{a}	1639^{abcdefghi}	1736^{abcdefghi}	1167^{abcdefgh}
S2P3	6.00^{a}	7.30^{ab}	8.80^{ab}	3.53^{abc}	4.80^{c}	4.17^{abc}	2042^{a}	1847^{a}	3257^{a}	1514^{abcdefghi}	2167^{fghi}	1528^{abcdefghi}
S2P4	6.87^{ab}	7.57^{ab}	8.77^{ab}	4.23^{abc}	4.33^{abc}	3.97^{abc}	1319^{a}	2361^{a}	3056^{a}	1528^{abcdefghi}	1931^{cdefghi}	1736^{abcdefghi}
S3P1	6.90^{ab}	7.70^{ab}	8.53^{ab}	3.80^{abc}	4.43^{abc}	4.43^{abc}	3068^{a}	3136^{a}	3160^{a}	2074^{efghi}	2580^{i}	1790^{abcdefghi}
S3P2	5.53^{a}	7.03^{ab}	6.1^{ab}	4.07^{abc}	4.40^{abc}	4.03^{abc}	2438^{a}	2926^{a}	3272^{a}	1827^{bcdefghi}	2333^{hi}	1605^{abcdefghi}
S3P3	6.87^{ab}	6.00^{a}	7.10^{ab}	3.88^{abc}	4.53^{abc}	3.53^{abc}	2975^{a}	2691^{a}	2494^{a}	2068^{efghi}	2000^{defghi}	1679^{abcdefghi}
S3P4	5.80^{a}	6.43^{ab}	7.30^{ab}	4.00^{abc}	3.57^{abc}	4.47^{abc}	2420^{a}	1704^{a}	3222^{a}	1864^{bcdefghi}	1358^{abcdefghi}	1901^{bcdefghi}
CV (%)		40.4			22.5			85			59.0	

Means on with the same letter on the column indicates no significant difference ($p \leq 0.05$) between the treatments using Duncan multiple range test (DMRT). Varieties: V1= Lyamungu 90, V2= JESCA and V3= KAT-B1, planting density: S1=200,000 plants ha^{-1}, S2=250,000 plants ha^{-1}, S3= 333,333 plants ha^{-1}, phosphorous rates: P1= 60 kg ha^{-1} , P2= 40 kg ha^{-1} , P3= 20 kg ha^{-1} and P4= 0 kg ha^{-1}.

supported large number of pods.

The maximum number of seeds per pod of 4.8 was recorded in JESCA variety when planted at a higher planting density 250,000 plants ha^{-1} and a phosphorous fertilizer at a rate of 20 kg ha^{-1}. The lowest number of seeds per pod was recorded in Lyamungu 90 variety when planted at a lowest planting density of 200,000 plants ha^{-1} and a phosphorous fertilizer at a highest rate of 60 kg ha^{-1}.

The findings of this study disagree with the results of Mulatu et al. (2017) who found that the highest mean number of seeds per pod was recorded at the lowest plant density of 125,000 plants ha^{-1} with the highest phosphorous level, while the lowest mean number of seeds per pod was obtained at the highest plant density, 250,000 plants ha^{-1} with no phosphorous application. Decreasing plant population density has increased number of seeds per pod across all the treatments. This variation might be due to low plant density encountered less intra-plant competition than high plant density and thus exhibited better growth that contributed to a greater number of seeds per pod. Similarly, these results disagree with Abdel (2008) who reported that number of seeds per pod increased with decreasing in plant density of faba bean. KAT-B1 variety resulted higher biomass yield of 6076 kg ha^{-1} when planted at a higher planting density of 250,000 plants ha^{-1} and a phosphorous fertilizer at a highest rate of 60 kg ha^{-1}. The lowest biomass yields of 806 kg ha^{-1} was recorded in JESCA variety when planted at a lowest planting density of 200,000 plants ha^{-1} and at a phosphorous fertilizer at a lowest rate of 0 kg ha^{-1}. The findings support the results of Mulatu et al. (2017) who found that higher biomass was recorded at the highest plant density, 250,000 plants ha^{-1} and the highest phosphorous level 69 kg ha^{-1} while the lowest biomass was recorded at the lowest plant density of 125000 plants ha^{-1} and the lowest phosphorous level of 0 kg ha^{-1}.

The highest total dry biomass at the highest density and the highest level of phosphorous might be due to the greater number of plants per unit area, and more application of phosphorus fertilizer may have cushioned the competitive effects of haricot bean plants as population density was increased which might have led to efficient use of phosphorus fertilizer at higher plant population densities and improvement in fodder and grain yields ha^{-1}. In agreement with this study, Getachew et al., (2006) reported increased dry biomass of faba bean with increased plant density.

The maximum grain yields of 2580 kg ha^{-1} was recorded in JESCA variety when planted at a highest planting density of 333,333 plants ha^{-1} and at a highest phosphorous fertilizer rate of 60 kg ha^{-1}, while the lowest grain yields of 544 kg ha^{-1} was recorded in Lyamungu 90 variety when planted at a lowest planting density of 200,000 plants ha^{-1} and at a highest phosphorous rate of 60 kg ha^{-1}. Application of phosphorus fertilizer may have cushioned the competitive effects of haricot bean plants as population density was increased which might have led to efficient use of phosphorus fertilizer at higher plant population densities and improvement in grain yields ha^{-1}.

The findings of the study disagree the results of Mulatu et al. (2017) who also recorded that the highest grain yield of haricot bean was obtained at a higher rate of phosphorous fertilizer and a higher planting density of 190478 plants ha^{-1}, while the lowest grain yield was recorded at the lowest plant density of 125,000 plants ha^{-1} and no phosphorous fertilizer (0 kg ha^{-1}).

Similarly, the findings agree with result of Ball et al. (2000), who also reported that, increasing plant population reduced yield of individual plants but increased yield per unit area of common bean. Furthermore, Hamidi, et al. (2010) also reported combined effects of plant density and fertilizer rate were positive and the increased levels of both parameters led to the increase in grain yield.

Conclusions

The findings of the study on yield response of bush bean varieties to different planting densities and rates of phosphorous fertilizer indicated significant improvement of yield productivity and other yield components of the three tested bush bean varieties. The tested bush bean varieties had varying yielding potentials with higher yields resulted by JECSA variety followed by Lyamungu 90 variety with KAT-B1 variety yielding lower than the other two varieties. The interaction of bush bean varieties and planting densities significantly increased the grain yields and other yield components. Also, the interaction of bush bean varieties and phosphorous fertilizer especially at higher rates only significantly increased the grain yields. The combination of bean variety, planting density and rates of phosphorous fertilizer on grain yield indicated that bean varieties planted at higher planting density of 333,333 plants ha^{-1} and applied with 60 kg ha^{-1} had the highest grain yields compared to the bush bean varieties planted at low density of 200,000 plants ha^{-1} without application of phosphorous fertilizer. Therefore, the findings suggest to farmers to opt for this combination in order to have more yield for more income and food security from farmer to national level.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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