IJCRT.ORG ISSN : 2320-2882
INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Effect of Lime, Phosphorus and Biofertilizer on Yield and Yield Components of Haricot Bean (Phaseolus vulgaris L.) in Southwestern Ethiopia

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ABSTRACT

Haricot bean (*Phaseolus vulgaris* L.) is one of the dominant pulse crops cultivated in the southwestern Ethiopia however, its yield is very low in comparison to average yield at the world level. One of the reasons for yield gap is soil acidity which reduces the availability of nutrients. Therefore, a field experiment was carried out during 2017 in South Bench, Gimbo and Andracha districts of southwestern Ethiopia with the objective of evaluating the effects of lime, phosphorus and *Rhizobium* biofertilizer applications on grain yield of haricot bean. The treatments consisting of two levels of lime, four levels of P_2O_5 and two levels of *Rhizobium* biofertilizer were laid out in randomized complete block design with three replications. Days to 50% flowering and 90% physiological maturity were delayed by the application of lime and *Rhizobium* in all the districts, whereas lime and P (69 P_2O_5 kg ha^{-1}) induced early maturity. There was significant interaction effect of treatments on the number of effective nodules, plant height and the number of branches per plant. The integrated use of treatments had significant effect on the number of seeds per pod, whereas the highest numbers of seeds per pod (6.29, 6.24 and 5.45) in South Bench, Gimbo and Andracha, respectively were recorded at 46 kg P_2O_5 ha^{-1} with lime and *Rhizobium*. The highest biomass yields (5852, 6309 and 4101 kg ha^{-1}) and grain yield (3229, 2958 and1746 kg ha^{-1}) were obtained at 46 kg P_2O_5 ha^{-1} applied with lime and *Rhizobium* at all the three locations mentioned above. Therefore, application of 46 kg P_2O_5 ha^{-1} with lime and *Rhizobium* biofertilizer can be recommended for the maximal grain yield in the study areas and similar agroecologies.

Key words: Biomass, Haricot bean, Lime, Phosphorus, *Rhizobium*, Soil acidity, Yield

INTRODUCTION

Haricot bean is one of the dominant pulse crops cultivated in the southwestern Ethiopia. The total haricot bean coverage in Bench Maji, Kaffa and Sheka zones is estimated at 2342.30, 6049.75 and 6049.75 ha with average annual production of 4125.41, 5043.82 and 5043.82 tones (CSA, 2012). The average productivity of haricot bean is 1.76, 0.83 and 0.90 ton ha^{-1} in Bench Maji, Kaffa and Sheka Zones, while the national average is 1.43 ton ha^{-1} (CSA, 2012). One of the reasons for yield gap is soil acidity which reduces the availability of P, Ca, Mg and affects biological N_2-fixation though the crop thrives well in pH range of 6.5-7.5 (Havilen *et al.*, 2014).

The most common management practice to ameliorate acid soils is through the surface application of lime (Bolan *et al.*, 2003). The major influence of lime when applied in the soil is on its ability to supply Ca^{2+} which is essential for plant growth and neutralizing the toxicity effects of H^+, Al^{3+} and Mn^{2+} in the soil (Havilen *et al.*, 2014). Lime may also increase soil pH resulting in suitable environment for survival of *Rhizobum* bacteria. Nevertheless, lime application should be combined with inorganic and/or organic fertilizer like *Rhizobium* biofertilizer in order to get adequate production (Shiferaw and Anteneh, 2014). Haricot bean in association with *Rhizobium* biofertilizer has the ability to convert nitrogen from the air into the soil and transform it into ammonium (NH_4), which can be used directly by the host plant. However, several reports have highlighted that N-fixation capability of *P. vulgaris* is low, especially if symbiotic association is constrained by various factors including inefficient strains capable of initiating the N-fixation process (Çigdem, 2011). In this regard, several research reports have indicated significant improvements in legume growth and yield in many parts of the world following inoculation with the appropriate inoculants (Havlin *et al.*, 2014; Habtamu *et al.*, 2017). Nevertheless, nitrogen fixation involving symbiotic association between *Rhizobia* in legumes is influenced by soil acidity that cause N deficiency in legumes including haricot bean as they depend solely on symbiotic N_2-fixation (Rice *et al.* 2001). Impairment of nodulation and N_2-fixation by legume-*Rhizobium* symbiosis is noticed when legumes are grown on acid soils (Mfilinge *et al.* 2014). Hence, unless efficient soil fertility management practices are designed and implemented, the productivity of haricot bean on such soils will remain poor.

However, scanty information is available on the effect of combined application of lime, phosphorus and *Rhizobium* biofertilizer on grain yield , quality of haricot bean and fertility of soil in the three administrative zones mentioned earlier in general, and South Bench, Gimbo and Andracha districts, in particular, wherein soil acidity is very chronic. Hence, this study was conducted with the objectives to investigate the above mentioned amendments on grain yield and yield components of haricot bean in three districts.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted on farmer's field at three locations, i.e. South Bench, Gimbo and Andracha districts in southwestern Ethiopia during 2016/17 cropping season under rainfed conditions (Table 1).

Table 1. Brief description of soil and climatic conditions of the experimental locations.

Location	Altitude (m.a.s.l)	Annual rainfall (mm)	Annual temperature ^{0}c	Soil reaction
South Bench	1384	1200 - 1800	20-29	Acidic
Gimbo	1650	1600-2200	18-21	Acidic
Andracha	1960	1800 - 2200	15.1– 27.5	Acidic

Treatments and experimental design

Treatments consisted of two levels of lime (with and without lime), four levels of P_2O_5 (0, 23, 46 and 69 kg P_2O_5 ha^{-1}) and two levels of *Rhizobium* biofertilizer (inoculated and un-inoculated) arranged in factorial combination using randomized complete block design (RCBD) with three replications. There were sixteen treatment combinations including the control. A 2m x 2m gross plot size was used as experimental unit accommodating five rows spaced at 40 cm distance between rows and 10 cm between plants with appropriate gaps to separate the blocks and plots. In accordance with specification of the design each treatment was assigned randomly to experimental units within blocks. The experimental field was ploughed and harrowed before planting. Calctic lime ($CaCO_3$) was hand broadcasted and thoroughly mixed with the soil one month before planting of haricot bean (variety Nasir). Two seeds were directly sown in each hole at 4 cm depth. Plant population was maintained by thinning at five leaf stage. Phosphorus fertilizer was applied at planting using triple superphosphate (46 % P_2O_5) and uniform dose of 18 kg N ha^{-1} was also applied at planting to all plots as a starter. All the recommended agronomic practices were followed uniformly in all the plots throughout the growing period.

Rhizobium biofertilizer inoculants preparation and seed inoculation

Haricot bean seed was washed with distilled water and surface sterilized with 70% ethanol. Seeds were then rinsed 4 times with tap water. Then, seeds were treated with carrier based inoculants containing *Rhizobium leguminosarum biover phaseouli* at the rate of 10 g per kg of seed (Rice *et al*., 2001). To avoid contamination, all *Rhizobium* un-inoculated treatments were sown prior to the inoculated treatments.

The composite soil samples drawn from experimental sites were analyzed at Tepi and Horticoop Soil Laboratory following standard procedures (Chapman, 1965).

Data collection

Nodulation parameters

Sampling for nodulation was performed by excavating entire root system of five randomly selected plants from the central rows at mid-flowering stage by a spade from 20 cm deep. The undisturbed soil samples were wrapped in plastic and transported to the laboratory where the soil was washed from the roots using gently running tap water. Care was taken to ensure that the roots and nodules were recovered intact. Nodules from crown region and lateral roots subsequently were removed manually from the roots. The effective number of nodules was counted and the mean value of five plants was recorded. Phenological data on days to 50% flowering and physiological maturity were collected when 50% of the plants flowered and physiological maturity attained. Growth data such as plant height and number of primary branches per plant were recorded. Yield and yield components such as number of pods per plant, number of grains per pod, biomass for which the harvested plants were sundried in an open air, grain yield for which yield of each plot was weighed after threshing at 11% moisture and finally yield per plot was converted to hectare basis, hundred-grain weight of randomly sampled 100 grains from each treatment were recorded. Finally, the harvest index was computed as ratio by dividing grain yield per plot to biological yield per plot.

Statistical analysis

Data were subjected to the analysis of variance (ANOVA) using statistical analysis software (Genstat, 18th ed). Separation of means was done using the LSD test at 5% probability level.

RESULTS AND DISCUSSION

Soil physico-chemical properties of the experimental sites

Selected physico-chemical properties of the soil of the experimental site was analyzed for composite soil (0-30 cm depth) samples collected from experimental sites before planting. Clearly, the soils are acidic particularly that of Andracha site which are highly acidic, and low in nutrients especially available P (Table 2).

Table 2. Physico-chemical properties of the experimental soils before planting.

Parameters	Study areas		
	South Bench	Gimbo	Andracha
pH (water)	5.24	5.17	4.55
pH (KCl)	4.38	4.23	3.73
Available P (mg/kg)	6.53	5.81	3.96
Total nitrogen (%)	0.28	0. 24	0. 18
Organic carbon (%)	2.22	2.01	1.82
Exch. acidity (meq/100g)	3.2	3.43	5.2
CEC (meq/100g)	34.3	31.33	29.6
Cu (mg/kg)	2.62	1.63	4.67
Fe (mg/kg)	172.36	177.21	330.03
Mn (mg/kg)	109.35	95.52	118.9
Zn (mg/kg)	8.59	6.93	3.88
Textural class	Clay loam	Clay loam	Clay loam

Impact of lime, phosphorus and *Rhizobium* biofertlizer on the production of effective nodules

The number of nodules increased with the increasing of rate of P integrated with lime and *Rhizobium*. Further, the analysis of variance showed that the interaction of lime, phosphorus (P) rate and *Rhizobium* biofertilizer and had significant ($p<0.05$) effect on the number of effective nodules (Table 3). The highest number of effective nodules per plant (148.10, 134.77 and 120.73) were recorded from the interaction of lime, 69 kg P_2O_5 ha^{-1} and *Rhizobium* biofertilizer in South Bench, Gimbo and Andracha districts, respectively. Not surprisingly, the lowest number of effective nodules per plant (31.56, 28.44 and 25.79) were recorded from the control plot in the respective districts.

Table 3. Imapct of lime, phosphorus and *Rhizobium* biofertilizer on nodulation of haricot bean.

L	P	R	Effective number of nodules per plant		
			South Bench	Gimbo	Andracha
0	0	0	31.56[a]	28.44[a]	25.79[a]
0	0	1	47.20[b]	42.65[b]	37.40[b]
0	1	0	57.63[bc]	51.87[bc]	46.04[bc]
0	1	1	6978[d]	63.04[d]	56.28[cd]
0	2	0	85.50[e]	77.58[e]	68.27[e]
0	2	1	98.90[f]	90.04[f]	80.67[f]
0	3	0	103.17[fg]	93.54[fg]	83.79[fg]
0	3	1	113.49[g]	102.78[g]	92.70[gh]
1	0	0	60.10[cd]	54.22[cd]	48.66[c]
1	0	1	82.69[e]	74.69[e]	66.24[de]
1	1	0	84.87[e]	77.22[e]	68.55[e]
1	1	1	112.91[g]	102.13[g]	91.80[gh]
1	2	0	105.36[fg]	95.81[fg]	86.59[fg]
1	2	1	137.41[hi]	124.22[hi]	114.13[i]
1	3	0	125.81[h]	113.75[h]	102.08[h]
1	3	1	148.10[i]	134.77[i]	120.73[i]
CV(%)			7.8	7.9	8.3
LSD (5%)			11.94	10.93	10.32
Sign.			*	*	*

Where, L= Lime, 0= Without lime and 1= With lime; P= Phosphorus, 0= No P application, 1= 23 P_2O_5 ha^{-1}, 2= 46 P_2O_5 ha^{-1} and 3= 69 kg P_2O_5 ha^{-1}; R= *Rhizobium*, 0= Un-inoculated and 1= Inoculated. Values superscripted by the same letter in a given column are not statistically different.

The positive response of number of effective nodules to P application could be due to the fact that P is required for plant growth, nodule formation and development, each process being vital for N_2-fixation (Debnath *et al.*, 2000). Specific nitrogenase activity decreases with the onset of P-deficiency. The magnitude of the specific nitrogenase activity is well correlated with legume tissue phosphorus concentration. In line with these results, Yoseph and Worku (2014) reported that application of P resulted in a significant increase in nodule number. Similarly, the high nodulation with increased rates of P might be due to phosphorus is needed in relatively large amounts to promote legumes growth; nodule number and nodule mass (Abdulkadir *et al.*, 2014).

Impact of lime, phosphorus and *Rhizobium* biofertlizer on phenological parameters

Days to flowering and maturity

Number of days to 50% flowering was significantly affected by lime, P rates and *Rhizobium* inoculation and their interaction. However, statistically effects of most of the treatments were not significant on days to 50% flowering in all the study areas (Table 4). Accordingly, the same minimum days (35.33) to 50% flowering were recorded from the application of P (69 kg P_2O_5 ha^{-1}) with lime in all districts. Whereas, the maximum days 48.67 and 52.67 for *Rhizobium* inoculated treatment only in South Bench and Andracha, respectively and 49.00 for the control plot in Gimbo were recorded for 50% flowering. *Rhizobium* inoculation significantly influenced the days required to reach in haricot bean. Inoculated treatment had taken relatively longer days to reach 50% flowering than the other treatments in both South Bench and Andracha districts.

The possible reason for delayed flowering with the *Rhizobium* inoculation might be due to the fact that inoculation enhanced nitrogen fixation and thereby increased N uptake by plants contributing to improved vegetative growth of haricot bean which caused delayed flowering. In agreement with this result, such delayed flowering with inoculation was also reported for chickpea (Verma *et al.*, 2013). On the other hand, the minimum days to 50% flowering recorded from the application of 69 kg P_2O_5 ha^{-1} only could be due to the effect of phosphorus to hasten the growth of plants. As for the physiological maturity, the number of days to maturity was significantly ($p<0.05$) affected by lime, *Rhizobium* biofertilizer, P rate and their interaction (Table 4). Plots which received lime and P (69 kg P_2O_5 ha^{-1}) without *Rhizobium* at South Bench, Gimbo and Andracha districts were early maturing which required 85.33, 85.33 and 91.33 days, respectively after planting. This result is in agreement with the findings of several workers who reported that days to maturity were significantly influenced by phosphorus application (Gefole *et al.*, 2011; Dereje *et al.*, 2015; Tessema and Alemayehu, 2015; Nebret and Nigussie, 2017).

Table 4. Effect of lime, phosphorus and *Rhizobium* biofertilizer on phenological parameters of haricot bean.

L	P	R	Days to 50% flowering			Days to 90% physiological maturity		
			South Bench	Gimbo	Andracha	South Bench	Gimbo	Andracha
0	0	0	45.33^{de}	49.99^{d}	49.33^{gh}	96.00^{ef}	104.67^{e}	95.67^{b}
0	0	1	48.67^{e}	46.67^{cd}	52.67^{h}	97.00^{ef}	94.33^{d}	94.67^{ab}
0	1	0	40.67^{abcd}	42.00^{abcd}	40.67^{abcde}	90.33^{abcd}	89.67^{abcd}	95.00^{ab}
0	1	1	42.67^{bcd}	43.00^{abcd}	43.00^{def}	93.33^{de}	91.33^{cd}	95.33^{ab}
0	2	0	38.33^{ab}	36.33^{ab}	36.33^{ab}	88.00^{abc}	87.33^{abc}	94.67^{ab}
0	2	1	40.57^{abcd}	40.00^{abc}	42.33^{cdef}	90.67^{bcd}	88.67^{abc}	93.00^{ab}
0	3	0	36.67^{a}	35.33^{a}	35.33^{a}	86.00^{ab}	85.67^{ab}	92.67^{ab}
0	3	1	38.33^{ab}	38.67^{abc}	43.67^{def}	88.00^{abc}	88.33^{abc}	94.00^{ab}
1	0	0	44.33^{cde}	43.67^{bcd}	44.67^{efg}	93.67^{de}	92.00^{cd}	95.67^{b}
1	0	1	45.67^{de}	44.33^{bcd}	47.00^{fg}	100.67^{f}	106.33^{e}	96.33^{b}
1	1	0	38.33^{ab}	41.33^{abcd}	40.67^{abcde}	92.00^{cde}	99.67^{bcd}	94.67^{ab}
1	1	1	39.00^{abc}	41.00^{abcd}	41.00^{bcde}	92.33^{cde}	99.67^{bcd}	93.33^{ab}
1	2	0	37.33^{ab}	36.33^{ab}	36.33^{ab}	89.67^{abcd}	87.00^{abc}	93.33^{ab}
1	2	1	39.67^{abc}	38.67^{abc}	38.67^{abcd}	89.67^{abcd}	89.00^{abc}	94.00^{ab}
1	3	0	35.33^{a}	35.33^{a}	35.33^{a}	85.33^{a}	85.33^{a}	91.33^{a}
1	3	1	39.67^{abc}	37.33^{ab}	37.33^{abc}	88.67^{abcd}	88.67^{abc}	93.33^{ab}
CV(%)			4.4	12.1	7.9	11.9	3.3	12.7
LSD(5%)			2.967	8.175	5.473	2.910	5.086	4.247
Sign.			*	*	*	*	*	*

Where, L= Lime, 0= Without lime and 1= With lime; P= Phosphorus, 0= No P application, 1= 23 P_2O_5 ha^{-1}, 2= 46 P_2O_5 ha^{-1} and 3= 69 kg P_2O_5 ha^{-1}; R= *Rhizobium*, 0= Un-inoculated and 1= Inoculated. Values superscripted by the same letter in a given column are not statistically different.

Impact of lime, phosphorus and *Rhizobium* biofertlizer on growth parameters

Plant height and production of primary branches

Application of P at different rates integrated with lime and *Rhizobium* inoculation resulted in significant variation in growth parameters in all the study areas (Table 5). Plant height was significantly ($p<0.05$) affected by the interaction effect of the treatments. The interaction effect of lime, *Rhizobium* and 69 kg P_2O_5 ha^{-1} P recorded significantly the highest plant height of 76.23, 68.89 and 61.68 cm in South Bench, Gimbo and Andracha districts, respectively. These were closely followed by lime, *Rhizobium* and 46 P_2O_5 ha^{-1} P which recorded (72.44, 65.60 and 58.61cm) but, statistically not significant. This positive growth response of haricot bean for application of P in acidic soil may be related with better availability of P as with application of lime and *Rhizobium*. In agreement with this result, Kisinyo *et al.* (2005) indicated that growth of plants increased in acid soil as application of P increased with lime. The increment of plant height due to *Rhizobium* inoculation might be due to the adequate amount of nitrogen fixed by the bacteria which promoted vegetative growth of the plants (Sajid *et al.*, 2011; Zafar *et al.*, 2011; Nyoki and Ndakidemi, 2014; Habtamu *et al*., 2017).

The interaction effect of treatments significantly ($p<0.05$) affected the production of primary branches per plant (Table 5). Number of primary branches per plant increased with the increasing of P application from 0 to 69 kg P $ha^{-1}$with lime and *Rhizobium*. The highest number of primary branches per plant (7.11, 6.44 and 5.79) was recorded from the plot treated with lime, *Rhizobium* and P rate of 69 P_2O_5 ha^{-1} in South Bench, Gimbo and Andracha districts, respectively followed by 6.59, 5.99 and 5.34 resulting from the interaction of lime, P rate of 46 P_2O_5 ha^{-1} and *Rhizobium* in all districts. These results are in agreement with those of Khadem *et al.* (2010).

Table 5. Impact of lime, phosphorus and *Rhizobium* biofertilizer on growth parameters of haricot bean.

L	P	R	Plant height (cm)			Number of primary branches per plant		
			South Bench	Gimbo	Andracha	South Bench	Gimbo	Andracha
0	0	0	33.27[a]	30.48[a]	27.60[a]	3.84[a]	3.44[a]	3.11[a]
0	0	1	42.24[ab]	38.36[ab]	32.94[ab]	4.35[ab]	3.88[ab]	5.52[ab]
0	1	0	47.40[bc]	43.11[bc]	37.53[bcd]	4.56[bc]	4.10[bc]	3.70[bc]
0	1	1	56.98[def]	51.78[def]	44.94[de]	5.04[cde]	4.55[cd]	4.05[cd]
0	2	0	53.04[cde]	48.11[cde]	41.85[cd]	5.51[efg]	4.88[de]	4.36[de]
0	2	1	63.59[fgh]	57.78[fgh]	50.70[ef]	5.98[ghi]	5.44[fg]	4.81[fg]
0	3	0	53.50[cde]	48.44[cde]	43.26[de]	6.31[hij]	5.66[gh]	5.08[gh]
0	3	1	61.53[efg]	55.89[efg]	49.79[ef]	6.49[ij]	5.74[gh]	5.17[gh]
1	0	0	42.70[b]	38.56[ab]	34.01[abc]	4.58[bc]	4.11[bc]	3.70[bc]
1	0	1	47.11[bc]	42.67[bc]	38.00[bcd]	4.94[cd]	4.44[cd]	3.96[bcd]
1	1	0	50.35[bcd]	45.67[bcd]	40.44[bcd]	5.15[def]	4.67[de]	4.24[de]
1	1	1	66.22[gh]	60.22[fgh]	53.36[fg]	5.62[fg]	5.10[ef]	4.59[ef]
1	2	0	62.90[fg]	57.00[fg]	51.12[efg]	5.91[gh]	5.36[fg]	4.85[fg]
1	2	1	72.44[hi]	65.60[hi]	58.61[gh]	6.59[j]	5.99[hi]	5.34[h]
1	3	0	67.25[ghi]	61.00[ghi]	54.64[fgh]	6.24[hij]	5.66[gh]	5.17[gh]
1	3	1	76.23[i]	68.89[i]	61.68[h]	7.11[k]	6.44[i]	5.79[i]
CV(%)			9.9	10.1	10.5	5.6	5.7	5.9
LSD(5%)			9.237	8.542	7.862	0.513	0.469	0.442
Sign.			*	*	*	*	*	*

Where, L= Lime, 0= Without lime and 1= With lime; P= Phosphorus, 0= No P application, 1= 23 P_2O_5 ha^{-1}, 2= 46 P_2O_5 ha^{-1} and 3= 69 kg P_2O_5 ha^{-1}; R= *Rhizobium*, 0= Un-inoculated and 1= Inoculated. Values superscripted by the same letter in a given column are not statistically different.

Further, this result is also in line with those of Ahmed *et al.* (2010), Namvar *et al.* (2013) and Mfilinge *et al*. (2014) where they reported that inoculation of chickpea with *Rhizobium* in field and in the glass house significantly increased number of primary branches per plant.

Application of lime, phosphorus and *Rhizobium* biofertlizer versus yield parameters

Pods and seed formation and seed development

The integrated use of treatments significantly ($p<0.05$) affected the number of pods per plant in all sites (Table 6). The highest number of total pods per plant (49.52, 47.11 and 33.76) was recorded at P application rate of 69 kg P ha^{-1} with lime and *Rhizobium* in South Bench, Gimbo and Andracha districts, respectively. The increase in number of pods with the increased P levels might possibly be due to adequate availability of P which might have facilitated the production of primary branches and plant height which might, in turn, have contributed to the production of higher number of total pods (Amare *et al.*, 2014; Meseret and Amin, 2014; Rafat and Sharifi (2015). In addition, the increment in number of pods per plant with liming combined with the *Rhizobium* and P may be related with neutralization of acid soil by lime which, in turn, increases availability of P for plant uptake (Kisinyo *et al.*, 2005).

Furthermore, application of P with lime and *Rhizobium* led to higher number of pods. This result was in agreement with that of Çigdem (2011).

As for the number of seeds per pod, there was significant variation due to application of lime, phosphorous and *Rhizobium* and their interaction in all the study areas (Table 6). Maximum number of seeds per pod (6.290, 6.24 and 5.45) in South Bench, Gimbo and Andracha respectively were recorded at 46 kg P ha^{-1} with lime and *Rhizobium*. On the other hand, the lowest number of seeds per pod (4.166, 5.51 and 3.67) was obtained from the control plots of the respective districts. In line with this result, Meseret and Amin (2014) and Habtamu *et al.* (2017) also reported the highest number of seeds per pod recorded with the application of high rate of P.

The interaction effect of lime, P and *Rhizobium* had highly significant ($p<0.001$) effect on hundred-seed weight in both South Bench and Andracha districts, whereas it showed only significant ($p<0.05$) effect in Gimbo (Table 6). The highest hundred-seed weight (24.08, 38.48 and 19.23) were recorded at P application rate of 46 kg P_2O_5 ha^{-1} with lime and *Rhizobium* in South Bench, Gimbo and Andracha districts, respectively followed by values of 24.04, 33.48 and 19.12 obtained from P application rate of 69 kg P_2O_5 ha^{-1} with lime and *Rhizobium*. The increase in seed weight with integrated use of 46 kg P_2O_5 ha^{-1} with lime and *Rhizobium* could be due to the fact that legumes including haricot bean have high P requirement as the main storage site of P is seed and due to the production of protein-containing compounds.

Table 6. Application of lime, phosphorus and *Rhizobium* biofertilizer versus yield components of haricot bean.

L	P	R	Number of pods per plant			Number of seeds per pod			Hundred-seed weight (g)		
			South Bench	Gimbo	Andracha	South Bench	Gimbo	Andracha	South Bench	Gimbo	Andracha
0	0	0	18.48^{a}	18.11^{a}	16.23^{a}	4.166^{a}	5.51^{a}	3.67^{a}	17.55^{a}	24.60^{a}	13.92^{a}
0	0	1	22.41^{ab}	22.00^{ab}	17.97^{ab}	4.397^{ab}	5.71^{ab}	4.11^{ab}	17.56^{a}	26.52^{a}	14.58^{b}
0	1	0	27.13^{ab}	26.67^{bc}	21.50^{abc}	5.050^{abc}	5.77^{ab}	4.68^{bc}	18.28^{ab}	27.89^{ab}	14.51^{b}
0	1	1	28.94^{bc}	28.44^{cd}	22.03^{abcd}	5.190^{abcd}	5.80^{ab}	4.52^{bc}	18.79^{b}	26.17^{a}	14.98^{c}
0	2	0	35.26^{cde}	34.67^{ef}	25.90^{cde}	5.720^{cd}	5.86^{ab}	4.63^{bc}	20.75^{cd}	28.93^{ab}	16.50^{e}
0	2	1	37.47^{def}	36.52^{efg}	27.77^{de}	5.852^{cd}	5.93^{ab}	4.80^{bcd}	21.18^{d}	29.45^{ab}	16.76^{f}
0	3	0	37.90^{def}	34.98^{ef}	29.77^{ef}	5.986^{cd}	5.88^{ab}	4.82^{cd}	21.08^{cd}	25.85^{a}	16.60^{ef}
0	3	1	41.38^{degf}	37.44^{fg}	29.45^{ef}	5.845^{cd}	6.04^{ab}	4.66^{bc}	22.48^{e}	29.00^{ab}	17.85^{g}
1	0	0	24.71^{ab}	24.28^{bc}	21.28^{abc}	4.900^{abc}	5.73^{ab}	4.16^{abc}	18.23^{ab}	27.46^{a}	14.58^{b}
1	0	1	27.26^{bc}	26.78^{bcd}	22.58^{bcd}	4.940^{abc}	5.73^{ab}	4.28^{abc}	17.55^{a}	27.19^{a}	13.92^{a}
1	1	0	33.52^{cd}	31.67^{de}	26.85^{cde}	5.317^{bcd}	5.80^{ab}	4.68^{bc}	20.25^{c}	28.27^{ab}	16.09^{d}
1	1	1	37.47^{def}	35.56^{ef}	26.92^{cde}	5.767^{cd}	5.91^{ab}	4.75^{bc}	22.61^{ef}	36.79^{bc}	18.02^{g}
1	2	0	42.54^{efg}	40.56^{gh}	31.53^{ef}	5.850^{cd}	6.15^{ab}	4.68^{bc}	23.96^{g}	32.30^{abc}	19.15^{i}
1	2	1	45.14^{fg}	43.44^{hi}	31.61^{ef}	6.290^{d}	6.24^{b}	5.45^{d}	24.08^{g}	38.48^{c}	19.23^{i}
1	3	0	44.16^{g}	43.11^{hi}	31.50^{ef}	5.990^{cd}	6.08^{ab}	4.37^{bc}	23.38^{fg}	31.79^{abc}	18.56^{h}
1	3	1	49.52^{g}	47.11^{i}	33.76^{f}	5.921^{cd}	6.20^{b}	4.77^{bcd}	24.04^{g}	33.48^{abc}	19.12^{i}
CV (%)			8.2	8.9	13.7	6.7	6.6	9.1	11.4	18.1	10.7
LSD (5%)			4.718	4.953	5.94	0.611	0.646	0.694	0.49	8.93	0.197
Sign.			*	*	*	*	*	*	**	*	**

Where, L= Lime, 0= Without lime and 1= With lime; P= Phosphorus, 0= No P application, 1= 23 P_2O_5 ha^{-1}, 2= 46 P_2O_5 ha^{-1} and 3= 69 kg P_2O_5 ha^{-1}; R= *Rhizobium*, 0= Un-inoculated and 1= Inoculated. Values superscripted by the same letter in a given column are not statistically different.

On this issue, Amare *et al.* (2014) reported that increasing doses of phosphorus from the control to 40 kg P_2O_5 ha^{-1} resulted in significant increment in 1000-seed weight of common bean. Similarly, Abdulkadir *et al.* (2014) reported that phosphorous fertilized *Phaseolus vulgaris* compared with the control treatment produced more pods which were better filled with heavier seeds. In addition, concerning *Rhizobium* inoculation, the study by Asad *et al.* (2004) wherein weight of 100 seeds increased significantly in the common bean inoculated with carrier-based as well as pure cultures of *Rhizobium* than that of un-inoculated treatment.

Biomass, grain yield and harvest index

Aboveground biomass yields were also significantly ($p<0.05$) affected by the application of lime, rate of P and *Rhizobium* and their interaction in all of the study areas (Table 7). Data showed that biomass yield was significantly increased in plots which received inoculated seeds with the application of lime and P as compared to their respective biomass yield in control plots. The use of inoculated seeds and application of lime and the rate of phosphorus at 46 kg P_2O_5 ha^{-1} resulted in maximum biomass yield (5852, 6309 and 4101 kg ha^{-1}) in South Bench, Gimbo and Andracha districts, respectively. The next highest biomass yields were obtained from inoculated seeds sown under the application of lime and phosphorus rate of 69 kg ha^{-1} in all the study sites. The recorded variation on biological yield of haricot bean might be attributed to the improvement in soil nutrient status due to increased applied rates of phosphorus integrated with the use of inoculated seeds and lime. The outcome of this trial was confirmed by the previous findings of Anetor and Akinrinde (2006), Gidago *et al.* (2011) and Tessema and Alemayehu (2015) who reported that the application of phosphorus significantly improved grain yield and biological yield of common been.

The analysis of variance of data on grain yield showed that interaction effect of application of lime, rate of P and *Rhizobium* was highly significant ($p<0.001$) on grain yield of haricot bean in all the study sites (Table 7). Accordingly**, a**pplication of lime integrated with phosphorus at the rate of 46 kg ha^{-1} and inoculated seeds resulted in maximum grain yield of 3229, 2958 and 1752 kg ha^{-1} in South Bench, Gimbo and Andracha districts, respectively followed by 3217, 2913 and 1746 kg ha^{-1} resulting from the interaction of lime, phosphorus at the rate of 69 kg ha^{-1} and *Rhizobium* applied in all respective districts. Thus, lime when combined with P fertilizer, it contributed improves soil physical conditions and nutrient use efficiency and bean yields. These yield trends also explain that liming alone cannot serve to achieve the maximum potential of an acid soil in contrast to the findings of Kisinyo *et al.* (2005) and Nekesa *et al.* (2011) who found positive response of bean grain yield to lime application either alone or combined with P fertilizer. Further, concerning to *Rhizobium*, legume inoculation is an established agricultural practice that has been used for more than a century to introduce *Rhizobia* into the soil to increase yield and soil fertility (Deaker *et al.*, 2004).

Table 7. Biomass, grain yield and harvest index of haricot bean as affected by lime, phosphorus and *Rhizobium* biofertilizer.

L	P	R	Aboveground biomass (kg/ha)			Grain yield (kg/ha)			Harvest index (ratio)		
			South Bench	Gimbo	Andracha	South Bench	Gimbo	Andracha	South Bench	Gimbo	Andracha
0	0	0	2362^{a}	2539^{a}	1656^{a}	1033^{a}	989^{a}	691.06^{a}	0.442^{bc}	0.393^{b}	0.362^{b}
0	0	1	2366^{a}	2540^{a}	1658^{a}	1117^{b}	1044^{a}	710.77^{a}	0.472^{c}	0.411^{bc}	0.378^{bc}
0	1	0	3908^{c}	4200^{cd}	2739^{cd}	1810^{e}	1692^{cd}	1005.27^{c}	0.463^{c}	0.402^{b}	0.370^{b}
0	1	1	4056^{cd}	4362^{d}	2842^{d}	1948^{g}	1756de	1055.24^{d}	0.480^{c}	0.417^{bc}	0.384^{bc}
0	2	0	5104^{e}	5489^{f}	3577^{f}	1879^{f}	1704^{cd}	1041.03^{d}	0.357^{a}	0.310^{a}	0.285^{a}
0	2	1	5259^{e}	5662^{fgh}	3685^{fgh}	1958^{g}	1830^{f}	1099.1^{f}	0.373^{ab}	0.324^{a}	0.299^{a}
0	3	0	5279^{ef}	5681^{fgh}	3699^{fgh}	1974^{g}	1821^{ef}	1089^{e}	0.371^{a}	0.322^{a}	0.296^{a}
0	3	1	5350^{ef}	5760^{gh}	3749^{gh}	1966^{g}	1837^{f}	1115.6^{f}	0.351^{a}	0.304^{a}	0.281^{a}
1	0	0	2557^{a}	2743^{a}	1792^{a}	1682^{c}	1572^{b}	947.7^{b}	0.660^{e}	0.575^{f}	0.528^{f}
1	0	1	3081^{b}	3308^{b}	2159^{b}	1759^{d}	1644^{bc}	983.08^{c}	0.570^{d}	0.496^{e}	0.456^{e}
1	1	0	3769^{c}	4056^{c}	2641^{c}	1971^{g}	2413^{g}	1452.08^{g}	0.685^{e}	0.594^{f}	0.548^{fg}
1	1	1	4377^{d}	4708^{e}	3067^{e}	2657^{h}	2857^{i}	1733^{j}	0.698^{e}	0.607^{f}	0.559^{g}
1	2	0	5212^{e}	5608^{fg}	3652^{fg}	2640^{h}	2468^{g}	1527^{i}	0.506^{cd}	0.439^{cd}	0.405^{cd}
1	2	1	5852^{g}	6309^{j}	4101^{j}	3229^{k}	2958^{j}	1752^{j}	0.551^{d}	0.468^{de}	0.432^{de}
1	3	0	5409^{ef}	5820^{h}	3790^{h}	2651^{h}	2571^{h}	1550.05^{i}	0.508^{cd}	0.441^{cd}	0.407^{cd}
1	3	1	5630^{fg}	6058^{i}	3945^{j}	3217^{k}	2913^{ij}	1746^{j}	0.553^{d}	0.481^{e}	0.443^{e}
CV(%)			11.17	9.7	2.7	16	15.2	12.4	4.6	4.5	4.5
LSD(5%)			195.9	211.2	137.27	27.62	40.08	24.05	0.038	0.032	0.030
Sign.			*	*	*	**	**	**	**	*	**

Where, L= Lime, 0= Without lime and 1= With lime; P= Phosphorus, 0= No P application, 1= 23 P_2O_5 ha^{-1}, 2= 46 P_2O_5 ha^{-1} and 3= 69 kg P_2O_5 ha^{-1}; R= *Rhizobium*, 0= Un-inoculated and 1= Inoculated. Values superscripted by the same letter in a given column are not statistically different.

Harvest index was highly significantly ($p<0.001$) affected by interaction of lime, rate of P and *Rhizobium*, in both South Bench and Andracha districts, while it showed only significant ($p<0.05$) effect in Gimbo district (Table 7). Accordingly, the mean harvest index values varied from 0.351, 0.304 and 0.281 for the plots which had been treated with 69 kg P ha^{-1} and lime to 0.698, 0.607 and 0.559 for lime, 23 kg P ha^{-1} and *Rhizobium* in South Bench, Gimbo and Andracha districts, respectively. The highest harvest index recorded for lime, 23 kg P ha^{-1} and inoculated seeds were due to the higher grain yield obtained with respect to lower biomass yield. Gidago *et al.* (2011) working on common bean reported non-significant effect of P application on harvest index.

CONCLUSION

The availability of plant nutrients in the soil is highly influenced by soil pH, soil nutrients such as N, Ca and most importantly, P which are deficient in acid soils. To complement ongoing efforts in this line, a field experiment was carried out during 2017 cropping season in southwestern Ethiopia at South Bench, Gimbo and Andracha districts on a farmer's field with the objective to evaluate the effects of lime, phosphorus and *Rhizobium* biofertilizer application on grain yield and yield opponents of haricot bean.

The results of analysis revealed that the interaction effects of lime, P and *Rhizobium* biofertilizer significantly ($p<0.05$) influenced the crop parameters tested in all the study districts. *Rhizobium* inoculation significantly influenced the days required to reach 50% flowering and inoculated treatment had taken relatively longer days to reach 50% flowering. Treatments which received lime and 69 kg P_2O_5 ha^{-1} without *Rhizobium* in all districts shortened maturity duration which might be due to the effect of phosphorus. In addition, liming acidic soils made P more available for the crop. The maximum days to 90% physiological maturity were recorded from the application of lime and *Rhizobium* biofertilizer in all the districts. This might be due to extended vegetative growth because of enhanced nitrogen obtained from biological nitrogen fixation.

Phosphorus applied at the rate of 46 kg ha^{-1} with lime and *Rhizobium* recorded maximum biomass yield in all districts, whereas the minimum was recorded from the control plots. Likewise, grain yield, harvest index, number of pods per plant, number of seeds per pod, and 100-seed weight were influenced by the interaction of the treatments. Accordingly, maximum number of seeds per pod and highest hundred-seed weight were recorded from the interaction of 46 kg ha^{-1} of P, lime and *Rhizobium* in all districts. Phosphorus applied at the rate of 46 kg P_2O_5 ha^{-1}, lime and *Rhizobium* resulted significantly higher grain yield of 3229, 2958 and 1746 kg ha^{-1} in South Bench, Gimbo and Andracha districts, respectively. The result of this study revealed that the interaction effect of application of lime with phosphorus applied at the rate of 46 kg P_2O_5 ha^{-1} and use of inoculated seeds resulted in higher grain yield over the absolute control and the other treatments. In general, maximum grain yield and biomass yield were obtained from the application of lime, 46 kg P_2O_5 and *Rhizobium* biofertilizer in all of the study locations. Therefore, these integrated treatments can be recommended for the study areas and similar agro ecologies.

ACKNOWLEDGEMENTS

The authors would like to thank Mizan-Tepi University, Ethiopia for financial support and zonal and district agricultural offices of the study area for their unreserved support.

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