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Response of Common Bean (Phaseolus vulgaris L.) to Application of Lime and Phosphorus on Acidic Soil of Areka, Southern Ethiopia

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Abstract

Soil acidity and low available P are the major soil chemical constraints which limit productivity of common bean on *Nitisols* of southern Ethiopia. In view of this, a field experiment was conducted at Areka Agricultural Research Centre in the 2014 main cropping season to assess the effect of lime and phosphorus fertilizer rates on the yield and yield components of common bean. Four levels of P (0, 10, 20, and 30 kg ha^{-1}) and four levels of lime ($CaCO_3$) (0, 0.9, 1.8, and 2.7 t ha^{-1}) were laid out in a factorial combination in randomized complete block design with three replications. Significantly the highest plant height (72.34 cm), leaf area index (3.257), effective nodules per plant (93.55), primary branches per plant (2.467), number of pods per plant (18.52), 100 seed weight (24.31 g), and seed yield (3176 kg ha^{-1}) were obtained from the highest rate of P (30 kg ha^{-1}). Similarly, the highest rate of lime (2.7 t ha^{-1}) resulted in significantly highest total number of nodules per plant (67.20) and 100 seed weight (24.61 g). On the other hand, none of the parameters were significantly affected by the interaction of the two factors. Moreover, the highest economic return (10,637 Birr ha^{-1}) was recorded from the combination of 2.7 t lime ha^{-1} and 30 kg ha^{-1} of P. In general, common bean responded positively to the application of both lime and phosphorus with more remarkable response to P application. Thus, it can be concluded that application of 2.7 t ha^{-1} lime and 30 kg ha^{-1} of P proved to be superior with respect to grain yield as well as economic advantage.

Keywords: $CaCO_3$, *Nitisols, Phaseolus vulgaris*, Phosphorus, Soil acidity

1. Introduction

Common bean is one of the most important food and export crops in Ethiopia and it is the source of protein and cash for smallholder farmers (Dereje *et al*., 1995). The current national production of common bean in Ethiopia is estimated at 366,876.94 hectares; with a total production of 4, 630, 08.490 tons and average productivity of 1.26 tons per hectare (CSA, 2013). It is also an important food and cash crop in Wolaita Zone where this study was conducted with an area of 19,768.25 hectares and average productivity of 1.00 ton per hectare (CSA, 2013). Major common bean producing regions are central, eastern, and southern parts of the country and in central Ethiopia; farmers grow early maturing white pea bean types for export as their cash crop (CSA, 2005).

Soil acidity is a significant problem of agricultural producers in tropical and subtropical regions which limit legume productivity (Bordeleau and Prevost, 1994). This is aggravated by the inherent poor fertility and acidity in most tropical soils (Okalebo *et al*., 2006). About 40% of the Ethiopian total land is affected by soil acidity (Mesfin, 2007). About 27.7% of these soils are dominated by moderate to weak acid soils (pH of 4.5 to 5.5), and around 13.2% by strong acid soils (pH <4.5) (Mesfin, 2007). In Wolaita Zone, from the total arable lands, about 32000 ha of land are reported to be moderately to highly acidic (Wolaita Zone Office of Agriculture unpublished yearly report 2013).

In acid soils, there are problems of both plant nutrient deficiencies and toxicities of Aluminum (Al^{+3}), Manganese (Mn^{+2}), and Hydrogen (H^+). Plant growth, and especially root growth, in acid soils is retarded by toxicities of (Al^{+3}), (Mn^{+2}), and H^+ (Crawford *et al*., 2008). Acidic soils cause poor plant growth resulting from aluminium (Al^{+3}) and manganese toxicity (Mn^{+2}) or deficiency of essential nutrients like phosphorus, calcium and magnesium. Restoring, maintaining and improving fertility of this soil is major priority as a demand of food and raw materials are increasing rapidly. Liming acid soil makes the soil environment better for leguminous plants and associated microorganisms as well as increase concentration of essential nutrients by raising its pH and precipitating exchangeable aluminium (Kisinyo *et al*., 2012). Availability of essential nutrients and biological activity in soils are generally greatest at intermediate pH at which organic matter break down and release essential nutrients like N, P and S is enhanced.

Soil acidity constrains symbiotic N_2 fixation (Munns, 1986), limiting *Rhizobium* survival and persistence in soils and reducing nodulation and causes nutrient imbalance (Foy, 1984). Increased soil acidity may lead to reduced yields, poor plant vigour, and nodulation of legumes (Kang and Juo, 1986). Wood *et al*. (1984) indicated that multiplication of *Rhizobium* in the rhizosphere and nodulation were inhibited at pH 4.3.

Ways of improving crop output from such soils include application of nitrogenous and phosphatic fertilizers, liming and addition of organic manure (Atiwag, 1992). The effects of soil acidity, acidification, and liming can be classified into three main categories that cannot always be sharply distinguished: the availability of nutrients, and toxic elements, and soil structure.

In highlands of Ethiopia, available P is potentially the limiting element in crop production (Tekalign and Haque, 1987) and 70 to 75% of the agricultural soils of these regions of the country are P deficient (Tekalign *et al*., 1988). Available P content of most soils in SNNPR of Ethiopia is less than 5 mg kg^{-1}, which is in the range of low P content (Kelsa *et al*., 1996), whereas the available P content of soils at Areka Agricultural Research Centre is very low ranging between 1.2 and 4.3 mg kg^{-1} in the surface soil layers indicating that improvement of available P content through amendments is needed to sustain productivity of these soils (Abayneh, 2003).

Like many legumes, common beans prefer well aerated, sufficiently drained soil with a pH of 6.0 to 7.5, the critical pH thresholds being 5.0 and 8.1 (Lunze *et al*., 2007). Soil pH relates to both soil's capacity to supply nutrients and to its aluminium and manganese toxicity problems (Kimani *et al*., 2010). Common beans are sensitive to high concentration of aluminium, boron and sodium (Horneck *et al*., 2007).

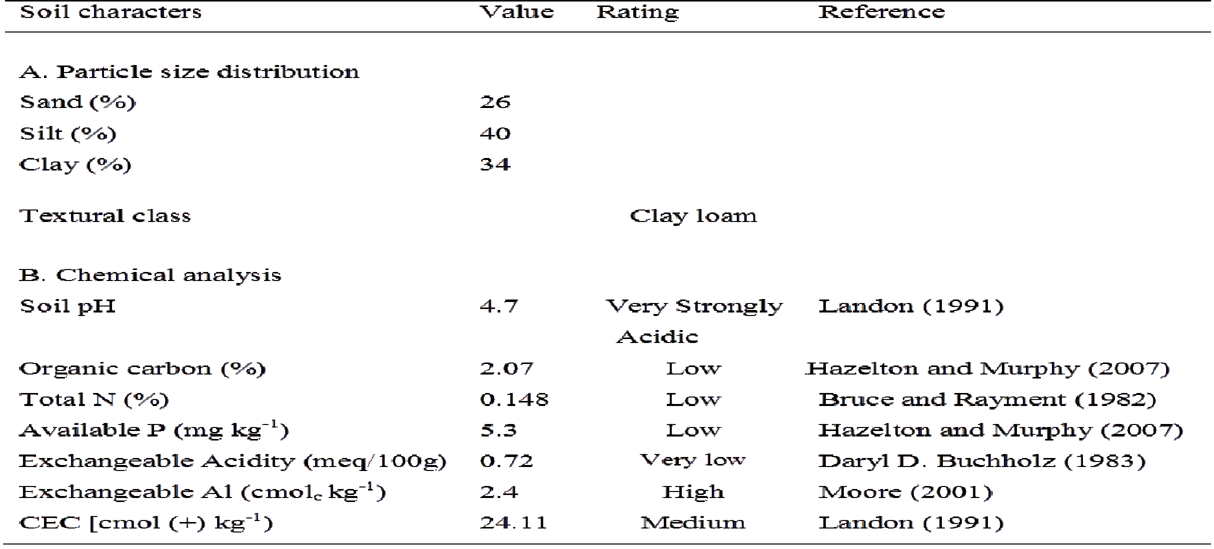
Acid soils constrain crop production but can be very productive if nutrients and lime are constantly applied and appropriate soil management is practiced (FAO, 2000).

The generally accepted practice to reduce soil acidity is the application of agricultural lime. Lime applied to acid soils raises the pH of soils, resulting in enhanced availability of nutrients, such as P, Ca, Mg, Mo etc. and improved crop yields (Kisinyo *et al*., 2009). Soil acidification and the associated P-deficiency are major soil degradation issues in many parts of southern region including Areka acidic soil. Thus, this study was conducted to assess the effects of liming and phosphorus fertilizer application on growth, yield components and yield of common bean; and to determine economically appropriate rates of lime and phosphorus for common bean production in the study area.

2. Materials and Methods

2.1. Description of the Study Area

Field experiment was conducted at Areka Agricultural Research Centre (ArARC) during June to October in 2014 main cropping season. ArARC is located at the distance of 300 km South of Addis Ababa at an altitude of 1830 meters above sea level (m.a.s.l.), latitude of 7^{o}4'24'' North and longitude of 37^{o}41'30'' East. It receives mean annual rainfall of 1520 mm in a bi-modal pattern with extended rainy season from March to September. The mean annual maximum temperature is 26 ^{o}C, whereas the mean annual minimum is 14^{o}C (Abay, 2011). The soil of the center is Alisols, which is very deep (>150 cm), very dark brown to black in colour and clay loam in texture. The pH (H_2O) of surface soil is 4.7 which is strongly acidic (Abayneh, 2003). The available P (Olsen) content of the center's soil is 4.2 mg kg^{-1}, which is rated as low for most of the crops. Total nitrogen content varied from 0.01 to 0.53% and is rated as very low to medium.



Soil characters	Value	Rating	Reference
A. Particle size distribution			
Sand (%)	26		
Silt (%)	40		
Clay (%)	34		
Textural class		Clay loam	
B. Chemical analysis			
Soil pH	4.7	Very Strongly Acidic	Landon (1991)
Organic carbon (%)	2.07	Low	Hazelton and Murphy (2007)
Total N (%)	0.148	Low	Bruce and Rayment (1982)
Available P (mg kg^{-1})	5.3	Low	Hazelton and Murphy (2007)
Exchangeable Acidity (meq/100g)	0.72	Very low	Daryl D. Buchholz (1983)
Exchangeable Al (cmol$_c$ kg^{-1})	2.4	High	Moore (2001)
CEC [cmol (+) kg^{-1})	24.11	Medium	Landon (1991)

2.2. Experimental Materials

Crop: The common bean variety Hawassa Dume was used for the study. The variety was released by Hawassa Research Centre of Southern Agricultural Research Institute in the year 2008 (MoARD, 2008). Hawassa Dume has medium sized dark red food types and white flower colour with a maturity period of 85-90 days with a determinate growth habit. The variety is adapted to an altitude range of 1100-1750 meter above sea level with rainfall of more than 500 mm in growing season. Hawassa Dume common bean variety was chosen for the study because it is high yielder, well adapted, preferred red seed colour and widely grown in the area by smallholder farmers in the study area.

Fertilizer/liming materials: Triple Super Phosphate (46% P_2O_5) and ground lime (85% calcium carbonate with fineness of 25% pass a 60-mesh screen made at Buee lime stone crushing factory) were used as sources of phosphorus and liming materials, respectively.

2.3. Soil Sampling and Analysis

Pre-planting composite soil sample from the experimental site was collected in a zigzag pattern from the depth of 0-30 cm before planting. Uniform volumes of soil were obtained in each sub-sample by vertical insertion of an auger. One kg of the composite sample soil was submitted to Hawassa Bureau of Agriculture Soil Testing Laboratory and analysed for organic carbon, total N, soil pH, available phosphorus, cation exchange capacity (CEC) and textural analysis using standard laboratory procedures

2.4. Treatments and Experimental Design

The treatments were factorial combinations of four phosphorus levels (0, 10, 20, 30 kg P ha^{-1}) and four calcium carbonate rates (0, 0.9, 1.8, and 2.7 t $CaCO_3$ ha^{-1}). The calcium carbonate ($CaCO_3$) rate of 1.8 t ha^{-1} was considered as standard in this experiment based on previous recommendation from Areka Agricultural Research Centre (Abay, 2011). Treatments were laid out in randomized complete block design (RCBD) with three replications. A gross plot size was 2.8 m x 3 m = (8.4 m^2) consisting of seven rows. One row from each side of the plot and one plot from both edges of the plot were left as border and one row was left for destructive sampling. Thus, the net plot size was 4 rows × 0.4 m × 2.8 m= 4.48 m^2. The spacing between blocks and plots was 1.2 m and 1 m, respectively.

2.5. Experimental Procedures

The land was ploughed by a tractor, disked, and harrowed by hand. The common bean variety was planted at inter-row spacing of 40 and intra row spacing 10 cm two seeds per hill.

The lime ($CaCO_3$) was evenly spread and incorporated into the soil 20 cm deep by using hoe one month before planting of common bean. Starter nitrogen fertilizer at the rate of 23 kg N ha^{-1} was applied in the form of Urea (46% N) to all the plots at planting whereas the whole rates of TSP as per the treatments were applied at planting time. All cultural practices such as weeding, cultivation, etc were applied uniformly to all plots as required.

2.6. Crop Data Collection

2.6.1. Growth parameters

Leaf area was measured just before flowering using leaf area meter (Model-CI-202-Area meter, CID, INC., U.S.A) by taking a destructive sample of five plants from a destructive row. Then, the leaf area index was calculated as the ratio of total leaf area to the respective ground area occupied by the crop (40 cm x 10 cm). Similarly, the total number of nodules was determined from five plants randomly taken from each plot at flowering by carefully digging and exposing with the bulk of root mass and nodules. The roots were washed and the nodules were separated from the soil and roots and the total number of nodules was determined by counting. Effective nodules were separated by their colors where a cross section of an effective nodule made with a pocket knife showed a pink to dark-red color, whereas a green and/or white color indicated non-effective nodulation.

Plant height was measured as the height of five randomly taken plants from the ground level to the apex of each plant at the time of physiological maturity from the net plot area. Likewise, number of primary branches per plant: was determined by counting the primary branches on the main stem from randomly taken five plants from the net plot area at physiological maturity.

2.6.2. Yield components and yield

Number of pods per plant was determined by counting the number of pods per plant of five randomly taken plants from each net plot area at harvest and then the number of seeds per pod was recorded from five randomly taken pods from each net plot at harvest. Hundred seed weight (g) was determined by taking weight of 100 randomly sampled seeds from the total harvest from each net plot area and the weight was adjusted to 10% moisture level.

Total above ground dry biomass was obtained from oven dried five sample plants per plot for 48 h at 85 ºC and the weight was converted to kg ha^{-1}. The seed yield (kg ha^{-1}) was recorded from the four central rows after drying and threshing and then the seed yield was adjusted to moisture level of 10%. Finally, yield per plot was converted to kg ha^{-1}. Harvest index (HI) was computed as the ratio of seed yield (kg ha^{-1}) to total above ground dry biomass.

2.6.3. Agronomic efficiency (AE): is defined as the quantity of grain yield per unit of nutrient applied.

AE (kg kg^{-1}) = $\underline{G_f - G_u}$

Na

Where G_f is the grain yield of the fertilized plot (kg), G_U is the grain yield of the unfertilized plot (kg), and Na is the quantity of P applied (kg).

The highest agronomic efficiency (AE) (10.90 kg kg^{-1}) was obtained at 10 kg P ha^{-1} P application. Besides this, significantly higher AE regardless of Lime treatments was recorded due to 10 kg P ha^{-1} than those obtained with other rates of P application. The value of AE indicated that for a unit of fertilizer P applied, the highest seed yield was produced at the lowest P rate (10 kg P ha^{-1}), whereas the lowest AE (4.78 kg kg^{-1}) was produced at the highest P rate (30 kg P ha^{-1}). The decreasing trend in AE with increasing P rates was also reported by Gifole et *al*. (2011) who found a declining trend of AE from 69.8 to 9.3 kg kg^{-1} at the rates of P ranging from 10 to 60 kg P ha $^{-1}$ on haricot bean.

Combined application of P and lime improved AE as compared to that obtained by P application alone. The highest AE (13.24 kg kg^{-1}) was obtained due to 2.7t lime with 10 kg P ha^{-1}. Similarly, Devi *et al*. (2012) reported higher AE (12.67 kg kg^{-1}) by combined application of single super phosphate and inoculation.

The agronomic efficiency showed that the grain yield of common bean responded better to the lowest level of P (10 kg P ha) which was in agreement with the results of Bationo and Buerkert (2001) who reported that small amounts of applied fertilizer optimized nutrient use efficiency. Moreover, significantly higher AE at 10 kg P ha^{-1} was recorded due to 2.7t lime ha^{-1} than other limed treatments. This might be due to the presence of plant growth promoting traits beside N_2 fixation in 2.7t lime ha^{-1} isolate.

2.7. Statistical Data Analysis

All the measured and recorded parameters were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD using Gen Stat 15th edition software (GenStat, 2012). Fisher's Protected Least Significance Difference (LSD) test at 5% probability level was used for mean comparison when the ANOVA showed significant differences for the treatments.

2.8. Economic Analysis

Variable cost of lime and phosphorus fertilizer was used for partial budget analysis. Price fluctuations during the production season were considered. An easier way of expressing this relationship is the calculation of the marginal rate of return, *i.e.* the change in net benefits divided by the marginal cost (i.e. the change in costs), expressed as a percentage. Marginal Rate of Return, which refers to net income obtained by incurring a unit cost of fertilizer, was calculated by dividing the net increase in yield of common bean due to the application of each rate to the total cost of lime and phosphorus fertilizer applied at each rate. This enables to identify the optimum rate lime and phosphorus fertilizer for common bean production (CIMMYT, 1988).

3. Results and Discussion

3.1. Growth and Nodulation of Common bean

3.1.1. Leaf area index

The main effect of phosphorus showed highly significant ($P<0.001$) effect on leaf area index of common bean, but the main effect of lime and the interaction were not significant (Table 1). The highest LAI (3.3) was recorded at 30 kg P ha^{-1} but the lowest LAI (1.3) was recorded from the rate of application of 0 kg P ha^{-1} (Table 1). In general, as P rate increased, the LAI increased which might be due to the fact that the cell elongation and division of the crop is highly affected by the amount of ATP synthesized in the plant cell which is again highly dependent on the availability and assimilation of inorganic phosphorus (Muller *et al.*, 2001). The highest physiological growth indices are achieved under high plant nutrition because photosynthesis enhanced by the growth and development of leaf area (Bennett, 1993). In agreement with this result, Tairo and Ndakidemi (2013) also reported that phosphorus have significantly increased the number of leaves, leaf area (LA) and leaf area index (LAI) on soybean.

3.1.2. Plant height

Analysis of variance showed highly significant ($P<0.01$) effect of P fertilizer application rate on plant height while lime rate and interaction did not show significant effect on plant height (Table 1). The highest plant height (72.34 cm) was observed at the highest rate of P application (30 kg P ha^{-1}) while the lowest plant height (37.88 cm) was recorded in control plots (Table 1). The increase in plant height in response to the increased P application rate indicates maximum vegetative growth of the plants under higher P availability. This positive growth response of common bean for application of P in acidic soil may be related with better availability of P as with application of lime. In agreement with this result, Kisinyo *et al.* (2005) indicated that growth of plants increased in acid soil as application of P increased with and without lime.

3.1.3. Number of primary branches

The phosphorus rate had highly significant ($P<0.001$) effect on number of primary branches per plant. However, lime rate and interactions effects were not significant on number of primary branches (Table 1). Number of primary branches per plant increased with the increasing of P application rate where increasing of P fertilizer rate from 0 to 30 kg P ha^{-1} enhanced the number of primary branches per plant from 1.58) to 2.5, respectively (Table 1). The increase in number of primary branches per plant in response to the increased P application rate indicates higher vegetative growth of the plants under higher P availability resulting in higher number of primary branches. The increment in number of branches per plant might be importance of P for cell division activity, leading to the increase of plant height and number of branches and consequently increased the plant dry weight (Khadem SA, *et al*., 2010). In agreement with this result, Shubhashree (2007) reported significantly higher number of branches per plant common bean with 75 kg P_2O_5 ha^{-1} over control.

Table 1. Main effects of lime ($CaCO_3$) and P rates on growth and nodulation of common bean

Treatments	LAI	NEN /plant	TNN/plant	PLH (cm)	NPB/plant
$CaCO_3$ (t ha^{-1})					
0	2.3	47.7	49.2^{b}	55.8	2.1
0.9	2.4	43.4	44.9^{b}	58.5	2.2
1.8	2.3	64.0	67.2^{a}	58.4	2.2
2.7	2.4	57.6	60.9^{ab}	56.6	2.3
Significance	ns	ns	*	ns	ns
LSD (0.05)	ns	ns	17.24	ns	ns
P rate (kg ha^{-1})					
0	1.3^{c}	8.0^{d}	8.2^{d}	37.9^{d}	1.6^{b}
10	2.3^{b}	41.5^{c}	43.2^{c}	56.6^{c}	2.3^{a}
20	2.6^{b}	69.8^{b}	73.1^{b}	62.5^{b}	2.3^{a}
30	3.3^{a}	93.6^{a}	97.7^{a}	72.4^{a}	2.5^{a}
Significance	**	**	**	**	**
LSD (0.05)	0.299	16.63	17.24	4.643	0.356
CV (%)	15.3	37.5	37.2	9.7	19.8

Means within a column followed by the same letter are not significantly different at 5% level of significance. *= significant at P = 0.05;** = significant at P = 0.01; ns = non- significant LAI=Leaf area index, PHT = Plant height; NPB/plant = number of primary branches per plant. NNEN/plant = number of non-effective nodules per plant and TNN/plant = number of total nodules per plant

3.1.4. Total number of nodules

Analysis of variance showed that the interaction of lime and P rate had non-significant effect on total number of nodules but the main effect of lime rate and phosphorus rate had significant ($P<0.05$) and highly significant ($P <0.01$) effect (Table 1). The highest total number of nodules (67.2) was recorded at the rate of 1.8 t ha^{-1} lime which was statistically at par with lime rate of 2.7 t ha^{-1} while the lowest total number of nodules (44.9) was recorded at the rate of 0.9 t ha^{-1} lime and was statistically at par with no application of lime (Table 1). The reason of high number of nodules with increasing lime application might be due to the existence of higher *Rhizobia* under increased soil pH due to liming. In agreement with this result, Crozier and Hardy (2003) reported that with proper liming, nodulation of legumes is enhanced, which improves nitrogen fixation. The bacteria (*Rhizobia*) in nodules on legume roots synthesize greater amounts of nitrogen from the soil atmosphere for use by the legume in places where soil pH is not too low Similarly, Hart *et al*. (2013) reported that nodulation depends on calcium supply and nodules on greenhouse-grown alfalfa roots increased from 35 to 70 per plant when soil pH increased from 5.3 to 5.8 and soil Ca increased. Moreover, liming an acidic soil to the recommended pH value often increases plant growth and P uptake (Debnath *et al.*, 2000).

The rate of phosphorus had highly significant ($P<0.01$) effect on total number of nodules Thus, the highest number of total nodules (97.7) was obtained from the highest P rate of 30 kg P ha^{-1} while the lowest number of total nodules (8.2) was recorded from no application P fertilizer (Table 1). The high nodulation with increased rates of P might be due to the fact that phosphorus is needed in relatively large amounts to promote legumes growth and yield, nodule number and nodule mass (Abdulkadir *et al.*, 2014). In particular, phosphorus deficiency is a major limiting factor for nodulation and nitrogen fixation (Sa and Israel, 1991). Phosphorus is needed in relatively large amounts by legumes for growth and has been reported to promote leaf area, biomass, yield, nodule number and nodule mass in different legumes (Kasturikrishna and Ahlawat, 1999).

3.1.5. Number of effective nodules

Phosphorus application had highly significant ($P<0.01$) effect on number of effective nodules per plant. Number of effective nodules per plant increased with the increasing of P application rate where the highest number of effective nodules per plant (93.55) was recorded at rate of 30 kg P ha^{-1} while the lowest number of effective nodules per plant (8.0) was recorded at rate of 0 kg P ha^{-1} (Table 1) 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 (Mulongoy, 1992). 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. Bacteroid mass per unit nodule mass, bacteroid N concentrations, plant cell ATP concentrations and energy charge were significantly lower in nodules of P-deficient plants (Sa and Israel, 1991).

In line with this result, Israel (1987) reported that nodule initiation had a high demand in P nutrition. Similarly, Yoseph and Worku (2014) also reported that application of P resulted in a significant increase in nodule number.

3.2 Yield Components Common Bean

3.2.1. Number of total pods per plant

Highly significant ($P < 0.01$) effect of P fertilizer application rate was observed on the number of total pods per plant while lime rate and interaction did not significantly influence the number of total pods (Table 2).

The highest number of total pods per plant (18.52) was recorded at P application rate of 30 kg P ha^{-1} whereas the lowest number of total pods (10.85) was obtained from control (Table 2). The increase in number of total 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 for the production of higher number of total pods. The increase in number of pods per plant could also be due to the increased leaf area with additional P being associated with more reproductive nodes (Saxena, 1984). A greater leaf area also results in a corresponding increase in assimilate supply which has been reported to determine pod number in field bean (Husain *et al.*, 1988). In conformity with this result, Singh and Singh (2000) reported significant increase in number of pods per plant of French bean (*Phaseolus vulgaris* L.) due to increased P fertilization. Similarly, Veeresh (2003) observed significantly more number of pods per plant of common bean at application rate of 75 kg P_2O_5 ha^{-1} as compared to control. Rafat and Sharifi (2015) also on green bean (*Phaseolus vulgaris* L.) reported maximum number of pods per plant (21) using 50 kg P ha^{-1}.

Table 2. The main effect of lime and phosphorus rates on number of pods per plant (NPP), seeds per pod (NSP) and 100 seed weight of common bean

Treatment	NPP	NSP	100 seed weight (g)
$CaCO_3$ (t ha^{-1})			
0	15.1	5.3	23.0^{b}
0.9	15.3	5.6	24.0^{a}
1.8	16.3	5.3	24.2^{a}
2.7	15.7	5.6	24.6^{a}
Significance	ns	ns	**
LSD (0.05)	ns	ns	0.69
P rate (kg ha^{-1})			
0	10.9^{c}	5.1	23.5^{b}
10	15.9^{b}	5.6	23.7^{ab}
20	17.1^{ab}	5.4	24.3^{a}
30	18.5^{a}	5.6	24.3^{a}
Significance	**	ns	*
LSD (0.05)	2.17	ns	0.69
CV (%)	16.7	12.5	3.5

Means within a column followed by the same letter are not significantly different at 5% level of significance. * = significant at P = 0.05;** = significant at P = 0.01; ns = non- significant

3.2.2. Number of seeds per pod

Neither the main effects of lime rate and P application rates nor their interaction effect were significant on the number of seeds per pod (Table 2). The number of seeds per pod ranged from 5.1 to 5.6. Thus, variations on the number of seeds per pod are highly affected by genetic factors than the management. In this line, Fageria and Santos (2008) reported that the number of seeds per pod of different common bean genotypes varied in the range of 3.1 to 6 and attributed the difference due to the genetic variation of cultivars. In conformity with this result, Gifole *et al*. (2011) reported that application of phosphorous did not show significant influence on number of seeds per pod on common bean.

3.2.3. Hundred Seeds weight

The main effect of lime rate had highly significant ($P < 0.01$) effect on hundred seed weight (Table 2). The highest hundred seed weight (24.61 g) was recorded at the highest rate of 2.7 t lime ha^{-1} whereas the lowest hundred seed weight (22.99 g) was recorded at the rate of 0 kg lime ha^{-1}. The main effect of phosphorus had also significant ($P<0.05$) effect on hundred seed weight. The highest hundred seed weight (24.3 g) was recorded at the P rates of 20 and 30 kg of P ha^{-1} and the lowest hundred seed weight (23.5 g) was recorded at the rate of 0 kg P ha^{-1} (Table 2). The increase in seed weight with increased rates of P could be due to the fact that legumes including common bean have high P requirement as the main storage site of P is seed and due to the production of protein containing compounds, in which N and P are important constituents, and P concentration in legumes is generally much higher than that found in grasses (Khan *et al.,* 2003). In agreement with this result, 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* when compared with the control produced more pods per plant which were better filled with heavier seeds.

3.3. Yields and Harvest Index

3.3.1 Above ground dry biomass yield

The result indicated a highly significant (P<0.001) effect of P application rate on the above ground dry biomass yield of the crop. However, lime application rate and interaction effects did not show significant effect on the above ground biomass yield of common bean (Table 3).

The result generally showed an increase in biomass production when P application increased from the lowest to the highest rate. The highest biomass yield (8135 kg ha^{-1}) was obtained at the rate of 30 kg P ha^{-1} while the lowest (4399 kg ha^{-1}) was produced at 0 kg P ha^{-1} (Table 3). Biomass production was not significantly influenced when the rate of P increased from 20 to 30 kg P ha^{-1}. However, it was significantly increased when the rate changed from 0 to 10 kg P ha^{-1} indicating the response of common bean to relatively lower rates of P. `The increase in above ground dry biomass yield at the highest rate of phosphorus might be attributed to the enhanced availability of P for vegetative growth of the plants. The adequate supply of P could have increased the number of branches per plant, and leaf area which in turn increased photosynthetic area resulting in higher dry matter accumulation.

This result was in agreement with the study by Shubhashree (2007) who reported that dry matter accumulation increased with application of phosphorus rates. Similarly, significant and linear increase in total dry matter production of common bean plant was observed due to increased phosphorus (Veeresh, 2003). Likewise, Meseret and Amin (2014) reported on common bean the maximum dry matter yield (75.5 g plant^{-1}) was recorded at application of P at 20 kg ha^{-1} whereas the minimum (28.9 g plant^{-1}) was recorded on control.

Table 3. Above ground dry biomass yield (AGDB), seed yield (SY), and harvest index (HI) of common bean as influenced by the main effect of lime and phosphorus rates

Treatment	AGDBM (kg ha $^{-1}$)	SY (kg ha $^{-1}$)	HI
$CaCO_3$ (t ha^{-1})			
0	5975	2279	0.38
0.9	6682	2539	0.39
1.8	7252	2668	0.38
2.7	6855	2628	0.39
Significance	ns	ns	ns
LSD (0.05)	993.1	317.4	ns
P rate (kg ha^{-1})			
0	4399^{c}	1715^{c}	0.40
10	6495^{b}	2478^{b}	0.39
20	7735^{a}	2744^{b}	0.36
30	8135^{a}	3176^{a}	0.39
Significance	**	**	ns
LSD (0.05)	993.1	317.4	ns
CV (%)	17.8	15.1	17.9

Means within a column followed by the same letter are not significantly different at 5% level of significance. * = significant at P = 0.05;** = significant at P = 0.01; ns = non- significant

3.3.2. Seed yield

Highly significant (P <0.01) effect of P fertilizer application rate on seed yield was observed while lime rate and the interaction effect were non- significant (Table 3).

Phosphorus application rate indicated progressive increases in seed yields with increase in P rates where the highest rate of P fertilizer (30 kg P ha^{-1}) gave the highest seed yield (3176 kg ha^{-1}) while the lowest seed yield (1715 kg ha^{-1}) was from no P application (Table 3). The highest response obtained from the highest phosphorous rate could be due to the fact that liming of acidic soils made the fixed phosphorous in the soil by Aluminium and Iron available to the plant and the addition of P might have fulfilled the requirement of the crop. On the other hand, the lowest yield of the control is probably because of fixation of P in the acidic soil that made P unavailable hence limited uptake by the common bean crop and consequently poor performance. The result indicated that applying phosphorus fertilizer remarkably increased growth and yield of common bean on soils which are naturally low in P. In conformity with this result, Birhan (2006) reported a significant yield increase of haricot bean to application of P Similarly, Amare *et al.* (2014) reported significant yield increase with increasing levels of phosphorus resulting in maximum yield (2326 kg ha^{-1}) for haricot bean at the rate 20 kg P_2O_5 ha^{-1} as compared to control and 40 kg P_2O_5 ha^{-1}. Gifole *et al*. (2011) also reported on common bean that the yield increased with increasing levels of P up to 40 kg P ha^{-1}.

3.3.3. Harvest Index

Harvest index was not significantly affected by the main effects of lime and P fertilizer application rates as well as by the interaction effect of lime and P application rates (Table 3). The harvest index ranged from 0.38 to 0.4. In line with this result, Meseret (2006) on mung bean and Gifole *et al*. (2011) on common bean reported non significant effect of P application on harvest index (HI).

3.4. Economic Analysis

From the partial budget analysis, the highest economic return (10,637 Birr ha^{-1}) was obtained from the application of 2.7 t lime ha^{-1} and 30 kg P ha^{-1} and the lowest economic return (-2,181 Birr ha^{-1}) was obtained from the application of 2.7 t lime ha^{-1} with the application of 0 kg P ha^{-1} (Table 4). The application of 2.7 t lime ha^{-1} and 30 kg P ha^{-1} resulted in 49.27% increment of return to the common bean sown only with 20 kg P ha^{-1} on farmers' condition.

Table 4. Summary of economic analysis of the effect of rates of lime and P on common bean

Lime rate (t ha^{-1})	P rate (kg ha^{-1})	Yield (kg ha^{-1})	TR	TC	Return (TR-TC)
0	0	1374	10992	12598	-1,606
0.9	0	2004	16032	13723	2,309
1.8	0	1757	14056	14848	-792
2.7	0	1724	13792	15973	-2,181
0	10	2399	19192	13240	5,952
0.9	10	2336	18688	14365	4,323
1.8	10	2562	20496	15490	5,006
2.7	10	2617	20936	16615	4,321
0	20	2626	21008	13882	7,126
0.9	20	2747	21976	15007	6,969
1.8	20	3001	24008	16132	7,876
2.7	20	2602	20816	17257	3,559
0	30	2719	21752	14524	7,228
0.9	30	3068	24544	15649	8,895
1.8	30	3350	26800	16774	10,026
2.7	30	3567	28536	17899	10,637

TR = Total revenue; TC = Total cost

Price of common bean per 100 kg at time of harvest = 900.00 Birr; Cost of 100 kg TSP = 1284.00 Birr; Price of Lime=125.00 Birr per Quntal.

4. Conclusion

The results showed that highest rate of P (30 kg ha^{-1}) gave significantly highest plant height, leaf area index, and number of total and effective nodules, number of primary branches, number of pods, 100 seed weight, dry biomass yield and seed yield. Similarly, the main effect of lime was significant on total number of nodules and 100 seed weight with the highest rate of lime (2.7 t ha^{-1}) resulted in the highest total number of nodules and 100 seed weight. The interaction of rates of lime and phosphorus were not significant on any of the parameters measured and recorded. The highest economic return (10637 Birr ha^{-1}) was recorded from the combination of 2.7 t lime ha^{-1} and 30 kg ha^{-1} of P. In general, common bean showed remarkable response to the application of phosphorus than liming which could have long-term effect. From this study, it can be concluded that in such an acidic soils application of 2.7 t lime ha^{-1} and 30 kg P ha^{-1} had resulted in higher seed yield and economic return. However, this study was done for one seasons at one location, the experiment has to be repeated over years to determine the long term effect of lime on the soil and on the crop.

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