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Response of Faba bean (Vicia faba) to Application of Phosphorus Fertilizer Levels at Lemu Bilbilo District, South-eastern Ethiopia

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Abstract
For two consecutive years (2017 - 2018), field experiments were carried out on different farm lands and provinces at Lemu-Bilbilo highland, southeastern Ethiopia, to assess, evaluate, and give recommendations of Phosphorus fertilizer requirement for faba bean crop by varying levels of phosphorus (0, 23, 46, 69, 92, 115 kg ha^{-1} P_2O_5, and 46 kg ha^{-1} P_2O_5 + 40 kg ha^{-1} K_2O) on growth performance and yield. The results revealed that phosphorus levels significantly affected number of tiller per plant, plant height, number of pods per plant, harvest index, grain yield and above ground biomass yield. The higher and lower number of tiller per plant (1.43 and 0.96) were recorded from plots received 69 and 0 kg P_2O_5 ha^{-1} respectively. The maximum and minimum plant height and number of pods per plant (119.6cm and 13.98) and (102.7cm and 11.66) were recorded from plots received 92 and 0 kg P_2O_5 ha^{-1} respectively. Similarly the highest and lowest grain yield and above ground biomass yield (4099.6 and 8127.4 kg ha^{-1}) and (3073.3 and 5713.8 kg ha^{-1}) were recorded from plots received 115 and 0 kg P_2O_5 ha^{-1} respectively. Generally the result indicated that application of phosphorus (69 kg P_2O_5 ha^{-1}) with grain yield (3996.8 kg ha^{-1}), is economically feasible treatment for improving productivity of faba bean crop under the conditions of the present study.
Keywords: Experiment, Phosphorus fertilizer, Faba bean, Lemu Bilbilo, South-eastern Ethiopia
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1. INTRODUCTION

No soil can provide high yields if it is not optimal in P (Rao *et al.,* 1999). Phosphorus is one of the essential macronutrients required by plants. As an essential plant nutrient, P is involved in a wide range of plant processes from permitting cell division to the development of a good root system to ensuring timely and uniform ripening of the crop. P is needed most by young, fast-growing tissues, and performs a number of functions related to growth, development, photosynthesis, and utilization of carbohydrates (Rao, 1996). P is a constituent of adenosine diphosphate (ADP) and adenosine triphosphate (ATP), two of the most important substances in life processes. ATP is a source of energy for physiological processes such as biological nitrogen fixation (Giller, 2001), photosynthesis, respiration, energy storage and transfer, cell division, cell enlargement, root development, flowering, seed formation, fruiting and improvement of crop quality (Sara *et al*., 2013). Because of the importance of P for plant growth and yield, many compound fertilizers such as NPK used to correct major deficiencies in soil P content as a major element.

Optimal plant growth requires P in the range of 0.3 - 0.5 % of dry matter during the vegetative growth stage. Dry matter P contents in excess of 1 % may be toxic for most crops. However, many tropical food legumes are more sensitive to excess P, and toxicity may occur at much lower shoot P contents, for example, 0.3 - 0.4 % in pigeon pea and 0.6 - 0.7 % in black gram (Bell *et al.,* 1990). The partial productive efficiency of P for grain or seed is higher at early growth stages than at later stages, because P is needed for tillering or branching. If sufficient P is absorbed at early growth stages, it will be redistributed to other growing organs.

Plant roots acquire P as phosphate, primarily in the form of H_2PO^{-4}, from the soil solution (Vance *et al.,* 2003). The concentration of H_2PO^{-4} in the soil solution is often low (2 to 10 μM) (Raghothama, 1999) and, consequently, the supply of H_2PO^{-4} to the root surface by diffusion is slow (Fitter and Hay, 2002). Therefore, P is one of the most unavailable and inaccessible macronutrients in the soil (Vance *et al.,* 2003) and frequently limits plant growth. For this reason, application of inorganic P fertilizers to infertility soils enhance crop productivity. Site-specific P application to lower testing regions may be a more profitable approach, although identifying lower P regions within fields is a challenge (Ferguson *et al.,* 2006). With increasing demand of agricultural production, phosphorus is receiving more attention as a non-renewable resource (Cordell *et al.,* 2009; Gilbert, 2009).

A unique characteristic of P is its low availability due to its slow diffusion and high fixation in acid and alkaline soils. As many African soils are old and highly-weathered, P fertilizers are required virtually everywhere for all crops. Legumes, in particular, tend to have a stronger requirement for P than cereals due to their less-branched and less fibrous root systems (Vanlauwe *et al.,* 2010). The higher protein content of grain legume seeds also requires greater amounts of photosynthetic to be used in synthesizing large amounts of protein (Sinclair and deWit, 1975), hence P availability is important to supply ATP for the crop. The increase of whole plant growth and plant nitrogen concentration in response to increased soil P supply have been noted for several leguminous species including faba bean (Israel, 1993).

2. MATERIALS AND METHODS

2.1. Experimental Site Description

The study was conducted at Lemu-Bilbilo highland, south-eastern Ethiopia. Geographically, it is located between 07^0 35' 300" to 07^0 27' 530" N, and 039^0 13' 899" to $039^0$15' 133" E with an elevation ranging 2226-2873 meters above sea level.

The average weather data recorded on the weather station located at Bekoji sub-station near the study area from the years 2017 and 2018 indicate that the mean annual rainfall were 956.6 and 803.5 mm respectively. The annual mean minimum and maximum air temperature for the consecutive years are (4.7, 2.9 ^{0}C) and (18.5, 20.3 ^{0}C) respectively.

2.2. Design and Treatments of the Experiment

The experiment was set in randomized complete block design by varying levels of phosphorus fertilizer (0, 23, 46, 69, 92, 115 kg ha^{-1} P_2O_5, and 46 kg ha^{-1} P_2O_5 + 40 kg ha^{-1} K_2O) with three replications. The size of each experimental plot was 2.6 m * 4 m (10.4 m^2) having ten rows, a distance of 1 m between plots and 1.5 m between blocks were left as a path. The recommended planting depth of 6 cm with spacing of 10 cm between plants and 40 cm between rows were used during sowing time. The faba bean variety used for the experiment was Moti. Diammonium phosphate (DAP) used as a source of phosphorus fertilizer which varied depending on treatments were applied as side banding at sowing time and other agronomic practices were kept uniform for all treatments.

2.3. Soil Sampling and Analysis

Surface soil, 0 - 20 cm depth, were collected from the entire experimental field before planting and after harvesting. The soil was air dried and made fine by using mortar and pestle. The fined soil was passed through 2mm sieve and the soil pH, Available P, Total N and Organic matter were determined at Kulumsa Agricultural soil Laboratory. Soil pH (H_2O) was measured by using a pH meter in a 1:2.5 soil: water ratio. Soil organic carbon was estimated by the Walkley-Black wet oxidation method. Total nitrogen was determined by the micro-Kjeldahl digestion, distillation and titration method, and available P was determined using the standard Olsen extraction method. Accordingly, The soil analysis result before planting indicated that the pH value was 4.83, very strongly acidic (Foth and Ellis, 1997), available phosphorus was 23.02 ppm, high (Olsen *et al.,* 1954), total N was 0.26 %, high and Organic matter 6.14 %, high (Berhanu, 1980) (Table 1).

Table 1. Mean Value of Soil data (0-30 cm) before Planting from the experimental sites in Lemu-Bilbilo District

pH (1:2.5)	Av.P (ppm)	Total N (%)	OM (%)
4.83	23.02	0.26	6.14

2.4. Agronomic and yield data collection

Data of seedling density, tiller per plant, plant height, number of spike per 50cm, number of pod per plant, number of seed per pod, grain yield, above ground biomass, and 100 seed grain weight were collected in five trials average from each plot. The plant height was measured from the base of the plant to the apical bud of plant and expressed in centimeters. Seedling density and number of spike per 50cm were taken by using 50cm by 50cm quadrant and recorded as a mean value. Pods per plant and seeds per pod counted from five randomly selected plants were converted to mean value and recorded as number of pods per plant and seeds per pod. Grain yield, above ground biomass and thousand seed grain weight were analyzed gravimetrically by using sensitive balance and recorded in units of gram.

2.5. Statistical Analysis

The ANOVA procedure of statistical analysis system (SAS Institute, 1996) was used for performing the significance of differences in seedling density, tiller per plant, plant height, number of spike per 50cm, number of pod per plant, number of seed per pod, grain yield, above ground biomass, and thousand seed grain weight parameters. A post hoc separation of means was done by least significant difference (LSD) test after main effects was found significant at $P \leq 0.05$.

2.6. Economic analysis

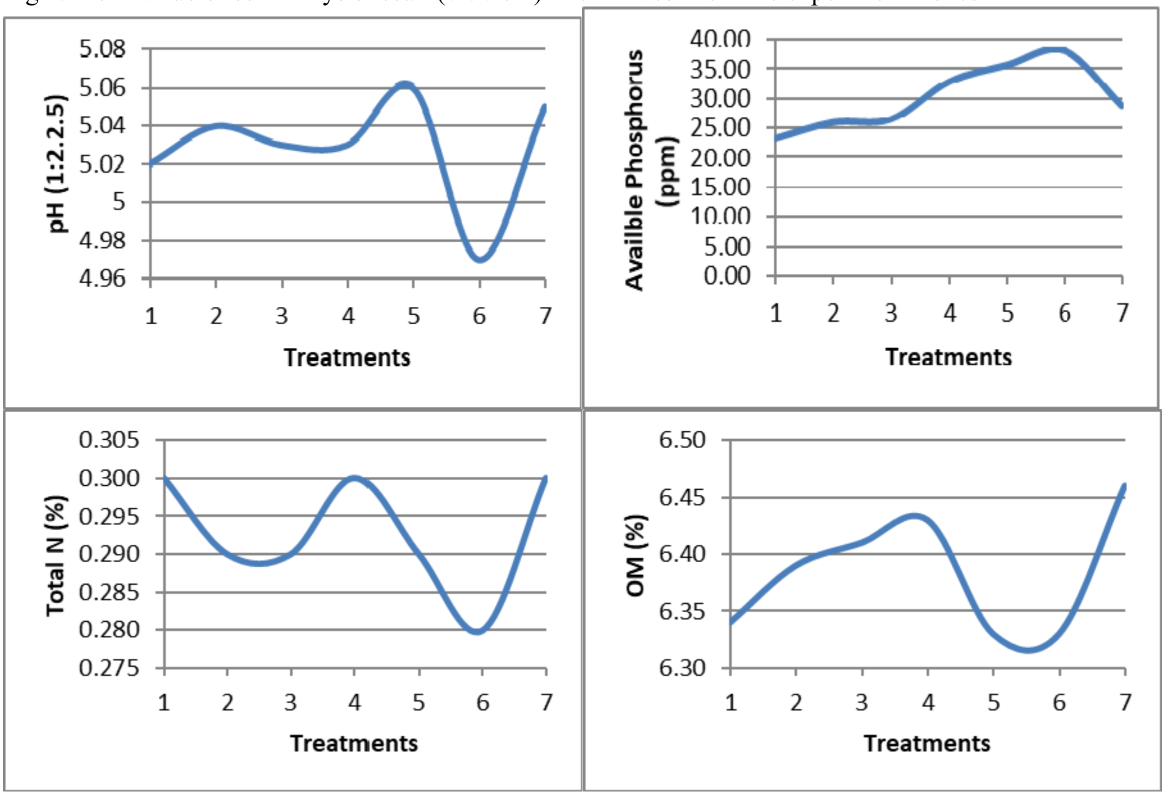
As farmers attempt to evaluate the economic benefits of shift in practice, partial budget analysis was done to identify the rewarding treatments. Yield from on-farm experimental plots was adjusted downward by 10 % i.e., 5 % for management difference and 5 % for plot size difference, to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment. Average market grain price of faba bean (ETB 8.00 kg^{-1}), farm-gate price of urea fertilizer (ETB 8.00 kg^{-1}), and DAP fertilizer (ETB 12.00 kg^{-1}) were used for fertilizer application.

3. RESULTS AND DISCUSSION

3.1. Soil Analysis

The post harvest soil analysis of experimental field showed that the acidity was decreased from 2.01 to 4.5 %, residual P increased from 1.2 to 39.1 %, total N increased from 7.1 to 13.3 % and organic matter increased from 3.0 to 4.9 % by the application of phosphorus fertilizer levels. The treatment received 46 kg ha^{-1} K_2O fertilizer up on 46 kg ha^{-1} P_2O_5 decreases pH by 0.4%, increase residual P, total N and organic matter by 7.95, 3.3 and 0.8 % respectively (Fig 1.).

Fig 1. Mean value of soil analysis result (0-30 cm) after harvest from the experimental sites



3.2. Effect of Phosphorus Fertilizer levels on growth of faba bean

Application of 69 kg ha^{-1} resulted in significant difference ($P<0.05$) in number of tiller per plant (1.43) for faba bean, which indicated that P_2O_5 at the rate of 69 kg ha^{-1} might be the optimum rate for improvement of number of tiller per plant. Further increase in phosphorus levels above 69 kg ha^{-1} decreases number of tiller per plant linearly (Table 2). Addition of 40 kg ha^{-1} K_2O over 46 kg ha^{-1} P_2O_5 increases number of tiller per plant by 12 %. This indicates that potassium fertilizer has a significant effect on tillering of faba bean. An increase in application of phosphorus fertilizer levels has no farther difference between treatment on plant height, number of pod per plant and number of spike per 50cm at harvest. The maximum number of seed per pod (3.02) was recorded at application of 69 kg ha^{-1} phosphorus fertilizer and the lowest at control (2.88). Application of 40 kg ha^{-1} K_2O decreases plant height, and increases number of pod per plant when compared to the treatment that was received only 46 kg ha^{-1} P_2O_5.

Table 3. Main effect of phosphorus fertilizer levels on Tiller per plant, Plant Height, number of pod per plant, number of seed per pod and number of spike per 50cm of faba bean

Treatments (kg ha^{-1} P_2O_5)	T/P	Ph (cm)	NP/P	NS/P	NS/50 cm
0	0.92c	102.7b	11.66c	2.88b	5.35b
23	1.17b	110.8ab	13.04ab	2.94ab	5.67ab
46	1.10bc	113.6a	12.53bc	2.99ab	5.9a
69	1.32ab	117.0a	13.89a	3.02a	6.05a
92	1.47a	119.6a	13.98a	3.0ab	5.96a
115	1.19b	118.8a	13.33ab	2.93ab	6.18a
46 + 40 K_2O	1.46a	110.5ab	13.3ab	2.97ab	6.02a
LSD (0.05)	0.3	9.7	1.3	0.1	0.5
CV (%)	28.1	13.0	15.0	6.6	13.9

Note: T/P = tiller per plant; Ph = plant height; NP/P = number of pod per plant; NS/P = number of seed per pod; Number of spike per 50cm

3.3. Phosphorus Fertilizer levels on yield and yield components of faba bean

Significantly higher mean grain yield and dry biomass yield (4099.6 and 8127.4 kg ha^{-1}) obtained with application of 115 kg ha^{-1} P_2O_5 and the lowest mean grain yield and dry biomass yield (3073.3 and 5713.8 kg ha^{-1}) were obtained at the control . Addition of K_2O fertilizer didn't made a difference compared to the treatment received only 46 kg ha^{-1} P_2O_5. The mean harvest index of faba bean was significantly ($P<0.05$) affected by different levels of phosphorus fertilizer (Table 3). Significantly higher mean harvest index (54.95%) was obtained from application of 46 kg ha^{-1} P_2O_5.

Mean thousand seed weight of faba bean was not significantly ($P>0.05$) affected by the main effect of different levels of P fertilizer. This result is in line with that of Nikfarjam and Aminpanah (2015) who suggested that effect of phosphorus application on 100 grain weight was not significant. yield and yield components of faba bean were generally decrease for treatments received 46 kg ha^{-1} P_2O_5 + 40 kg ha^{-1} K_2O fertilizers when compared to the treatment that was
received only 46 kg ha^{-1} P_2O_5 fertilizer.

Table 3. Main effect of phosphorus fertilizer levels on grain yield, Above ground dry biomass, harvest index and thousand seed weight of faba bean

Treatments (kg ha^{-1} P_2O_5)	GY (Kg/ha)	BY (Kg/ha)	HI (%)	TKW (gm)
0	3073.3d	5713.8d	54.24ab	834.95
23	3552.9c	6773.3c	53.49ab	834.35
46	3772.0abc	6917.5bc	54.95a	830.73
69	3996.8ab	7539.6ab	53.99ab	837.35
92	4048.6a	7678.5a	53.93ab	830.49
115	4099.6a	8127.4a	51.33b	836.65
46 + 40 K_2O	3598.2bc	6734.2c	54.03ab	835.89
LSD (0.05)	401.8	741.7	3.3	ns
CV (%)	16.3	15.9	9.3	1.5

Note: GY = grain yield; ABY = biomass yield; HI = harvest index; TKW = thousand seeds weight

3.4. Economic Feasibility of Faba Bean Production

As the result of partial budget analysis, the highest net benefit was obtained from the application of 69 kg ha^{-1} P_2O_5 was ETB 24862.4 ha^{-1} followed by application of 46 kg ha^{-1} P_2O_5 (ETB 23664 ha^{-1} (Table 4).

Table 4. Partial budget analysis of phosphorus fertilizer application for faba bean

Treatments (kg ha^{-1} P_2O_5)	Adjusted grain yield (kg ha^{-1})	Gross benefit (kg ha^{-1})	Total variable cost (kg ha^{-1})	Net benefit (kg ha^{-1})	MRR (%)
0	3073.30	24586.4	5312	19274.4D	
23	3552.90	28423.2	5912	22511.2D	
46	3772.00	30176	6512	23664	192.13
69	3996.80	31974.4	7112	24862.4	199.73
92	4048.60	32388.8	7712	24676.8D	
115	4099.60	32796.8	8312	24484.8D	

D =dominated, Urea fertilizer price = 8.00 Birr kg^{-1}, DAP fertilizer price = 12.00 Birr kg^{-1}, faba bean grain price = 8.00 Birr kg^{-1}, MRR = marginal rate of return.

4. CONCLUSION

The post harvest soil analysis of experimental field showed that the acidity was decreased from 2.01 to 4.5 %, residual P increased from 1.2 to 39.1 %, total N increased from 7.1 to 13.3 % and organic matter increased from 3.0 to 4.9 % by the application of phosphorus fertilizer levels. The treatment received 46 kg ha^{-1} K_2O fertilizer up on 46 kg ha^{-1} P_2O_5 decreases pH by 0.4 %, increase residual P, total N and organic matter by 7.95, 3.3 and 0.8 % respectively.

Application of 69 kg ha^{-1} resulted in significant difference ($P<0.05$) in number of tiller per plant (1.43) for faba bean, which indicated that P_2O_5 at the rate of 69 kg ha^{-1} might be the optimum rate for improvement of number of tiller per plant. Addition of 40 kg ha^{-1} K_2O over 46 kg ha^{-1} P_2O_5 increases number of tiller per plant by 12 %. This indicates that potassium fertilizer has a significant effect on tillering of faba bean. The maximum number of seed per pod (3.02) was recorded at application of 69 kg ha^{-1} phosphorus fertilizer and the lowest at control (2.88). Application of 40 kg ha^{-1} K_2O decreases plant height, and increases number of pod per plant when compared to the treatment that was received only 46 kg ha^{-1} P_2O_5.

Application of 115 kg ha^{-1} P_2O_5 gave significantly higher mean grain yield and dry biomass yield (4099.6 and 8127.4 kg ha^{-1}) obtained with application of 115 kg ha^{-1} P_2O_5 and the lowest mean grain yield and dry biomass yield (3073.3 and 5713.8 kg ha^{-1}) were obtained at the control. Addition of K_2O fertilizer didn't made a difference compared to the treatment received only 46 kg ha^{-1} P_2O_5.

Higher net economic return of ETB 24862.4 ha^{-1} and ETB 23664 ha^{-1} were obtained from the application of 69 and 46 kg P_2O_5 ha^{-1} for faba bean production. Accordingly, treatments with application of 46 kg P_2O_5 ha^{-1} (192.13%^{MRR}), and 69 kg P_2O_5 ha^{-1} (199.73%^{MRR}) are well above the minimum acceptable rate of return. Generally the result indicated that application of phosphorus (69 kg P_2O_5 ha^{-1}) with grain yield (3996.8 kg ha^{-1}), is economically feasible treatment for improving productivity of faba bean crop under the conditions of the present study.

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