Effect of Lime and Different Phosphorus Fertilizer Source on Faba bean (*Vicia fabae L.*) And Chemical Properties of Acidic soil of Ethiopia

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Abstract

Acidic soils cause poor plant growth resulting from aluminum (Al^{+3}) and manganese (Mn) toxicity or deficiency of essential nutrients like phosphorus, calcium, and magnesium. Hence, improving the fertility of this soil through appropriate management is a major priority as the demand for food and raw materials is increasing rapidly. To this end, a field experiment was carried out at Gozamen district of the Western Amhara region to determine the effect of different phosphorous fertilizer levels and liming on grain yield of faba bean (Vicafaba L.) and chemical properties of the soil. The experiment had two sets; lime and un-lime which were conducted separately. The treatments include a combination of different phosphorous fertilizer type with eight levels (0, GPAPR 146, 219+ 26 UREA, MOHP 175, 116+26 UREA, NAFAKA 287, 191 + 26 UREA, and NPSZnB 136+26 UREA kg ha-1) and 1/4th of recommended lime. The experiment was laid in a randomized complete block design with three replications of each. The highest grain yield 1352 kg ha^{-1} was obtained with the application of lime with 287 NAFAKA kg ha^{-1} followed by the application of 191 kg ha^{-1} without lime which recorded a grain yield of 1337 kg ha^{-1}. At Gozamen the net benefits 14781.5 ETB ha^{-1} with marginal rate of return 895.1% and 21657.5 ETB ha^{-1} with marginal rate of return 92.7% were obtained from the combination of 287 NAFAKA kg/ha plus lime and 191 kg ha^{-1} NAFAKA without lime respectively.

Keywords: *Fertilizer, Grain yield, Lime, Phosphorus, Soil pH*

Introduction

Faba bean (*Viciafabae* L.) fixes atmospheric nitrogen in symbiosis with *Rhizobium leguminosarumbv.viciae* (Hardarson et al 1991.) It grows on loamy to clay loam soil types but prefers deep, loamy soil with neutral to alkaline pH (7.0-9.0). Typical environmental stresses faced by the legume nodules and the symbiotic partners may include water stress, salinity, soil pH, temperature, heavy metals, and so on (Amanuel et al 2000). The average annual yield of faba bean is 21.9 Q/ha in Ethiopia (CSA, 2017). N_2-fixation in root nodules is sensitive to extremes of pH: nodulation & N-fixation are reduced where pH < 5.5 & >8.0 or with excessive salinity.

Soil acidity and its problem are common in all regions where precipitation is high enough to leach appreciable amounts of exchangeable bases from the soil surface. Although acidification is a natural process in many soil environments, agricultural practices, environmental pollution, mining and other human activities have aggravated the process (Oguntoyinbo *et al*., 1996; Curtin and Syers, 2001). Its severity is extremely variable due to the effects of parent materials, landform, vegetation, and climate pattern (Rowell, D. L., 1994). Its effects on crop growth are those related to the deficiency of major nutrients and the toxicity of aluminum (Al), manganese (Mn), and hydrogen (H) ions in the soil to plant physiological processes (Mesfin, 2009). In order to secure sustainable crop production and reasonable yield, acidic soils have to be corrected by the addition of agricultural lime to a pH range that is suitable for faba bean (Mesfin, 2009). The beneficial effects of liming soil are neutralization of exchangeable Al, increase Ca, Mg, P, and Mo availability, stimulate microbiological activity in soil; improve the physical structure of soil by clumping together or flocculation, clay into more stable aggregates (Fageria and Baligar, 2008). Liming raises the soil pH by adding calcium & magnesium to soil and causes the aluminum and manganese to go out from the soil solution back in to precipitate then solid (nontoxic) chemical forms. The lime requirement will vary depending upon the types of soil, the desired change in pH, buffering capacity of the specific soil, type of liming material, and the fineness of texture of the lime material (Birhanu, 2010).

Phosphorus P is one of the essential macronutrients that determine crop growth and productivity. However, its deficiency is one of the largest constraints on crop productivity in soils of the humid tropics because of high P fixation by iron (Fe) and aluminum (Al) oxides (Kamprath, 1984). Therefore, an appropriate P-management system is increasingly becoming important in marginal acid soils to enhance crop productivity. One of the appropriate P-management methods is applying the optimum rate of P and this significantly improves plant growth (Shaikh et al.,2008). Moreover, the addition of lime to acid soils has long been widely adopted as the amelioration strategy for many years to improve crop production which is rarely used in Ethiopia. The appropriate combination of lime and P fertilizer is, therefore, an important strategy for improving crop growth in acid soils. There is, however, a scarcity of information on the interactive effects of lime and P fertilizer application on crop performance in western Amhara Ethiopia. Phosphate rock is recommended for application to acid soils where phosphorus is an important limiting nutrient on plant growth. The objective of this study was, therefore, to investigate the interactive effects of lime and P fertilizer on faba bean grain yield on the selected soil chemical properties under acid soil conditions in Western Amhara, Ethiopia.

Materials and Methods

Description of Study Area

The study was conducted for two consecutive years during 2016 to 2017 main cropping seasons in Gozamen districts of East Gojjam zone in western Amhara, Ethiopia. Gozamen is located at s above sea level in western Amhara, Ethiopia. The site is typically characterized by highland with a cool subtropical climate.

The area (Gozamen) receives an annual mean rainfall of 1145 mm with the unimodal distribution of June to September. The site with an acidity problem (pH <5.2) and with no liming history was selected for this experiment. Some of the chemical characteristics of the experimental site are summarized in Table 1.

Table 1. soil chemical properties of the experimental site

Location	pH	P/ppm	OC%	OM%	Exch acidity meq/100gm	Exch Al meq/100gm
Gozamen	5.1	8	1.6	2.82	1.5	0.9

Note: P=phosphorus, OC=Organic carbon, OM=Organic matter

Experimental setup

The experiment was conducted separately in two sets (Lime & un-lime) in a randomized complete block design with three replications of each. Four types of P fertilizer with eight levels (0, 146, 219 GPAPR + 26 UREA, 175, 116 MOHP +26 UREA, 287, 191 NAFAKA + 26 UREA, and 136 NPSZnB +26 UREA kg ha^{-1}) and 1/4th of recommended lime based on exchangeable acidity (Al^{3+} plus H^{1+}) adapted from (Kamprath, 1984). Lime was applied uniformly in a row by hand to every year. The experimental plots were kept permanent to observe the residual effects of phosphorous and lime application over years. The entire dose of phosphorous and the recommended N rate (26 kg/ha) were applied at planting. Gross and net plot sizes were 3 m × 4 m and 3 m × 3.2m respectively. Faba bean variety Wolkie was used as a test crop.

Soil sampling

Before planting and before application of lime composite soil samples were taken from the experimental site using a soil auger from 0-20 cm soil depth. At harvesting, soil samples were collected from each treatment and independently analyzed. Soil samples were air-dried under shade, grounded by mortar & pestle, and sieved to pass through 2 mm mesh for further chemical analysis.

Soil analysis

The soil pH was determined using a glass electrode pH meter in 1:2.5 soils to water ratio and exchangeable acidity (Al^{+3} and H^{+}

(Keeney et al 1982). Available phosphorous was determined by Olsen (Olsen & Sommer, 1982). Soil organic carbon (SOC) was determined following the wet digestion method used by Walkley and Black (Van Reeuwijk, 1992)

Agronomic Data Collection and Interpretation

Dry biomass and grain yield were collected at physiological maturity. Analysis of variance (ANOVA) for straw and grain yield data were conducted using SAS 9.2 version (SAS, 2008). In conditions where ANOVA is significant, the treatment means were compared using the Least Significance Difference test (LSD).

Economic Analysis of Treatment

Partial budget analysis of treatments was done according to CIMMYT (1988). The mean grain yield data of faba bean which was produced by each treatment over two experimental years (2016 and 2017) was used for the partial budget analysis. The mean grain yield data were further adjusted down by 10% to minimize the yield gap that may occur due to plot management differences by researchers and farmers (CIMMYT, 1988). The average prices of relevant data which were needed to do the partial budget analysis were collected from different sources. Thus, the field price of 1 kg of faba bean in 2018 at the local market was 22 Ethiopian Birr (ETB) and was taken as a field price of faba bean. Thus, the current price of

Urea 12.76 ETB kg^{-1}, NPSZnB 13.82 ETB kg^{-1}, KCl 10 ETB $kg^{-1}$and lime 1.6 ETB $kg\text{-}^{1}$. The price of different phosphorous source fertilizers (NAFAKA, MOHP, and GPAPR) were calculated by the current price NPSZnB fertilizer.

Results and Discussions

Grain yield

The analysis of variance indicated that lime and P fertilizer application not significantly affected Fababean grain yield in both years (Table 2). The initial soil pH of our experiment area was 5.1. Hence faba bean grain yield was low as compared to the crop potential probably due to acidity. According to (Hardarson et al 1991.) Faba bean grows on soil with neutral to alkaline (7.0-9.0). The effect of lime and P fertilizer application on grain yield of faba bean was found significant only during the first year (Table 2). The highest faba bean grain yields 1352 kg ha^{-1} on combined analysis was obtained from the application of $1/4^{th}$ of the recommended lime based on exchangeable acidity with 287 kg/ha NAFAKA phosphorous fertilizer followed by a full dose of MOHP under a limed condition which recorded the grain yield of 1326 kg ha^{-1} (Table 2).

Many researchers also revealed that lime application improved the grain yield of crops (Liu et al., 2004; Achalu et al., 2012; Caires et al., 2005). According to Achalu et al. (2012), the increase in crop yield through the application of lime may be attributed to the neutralization of $Al^{3+,}$ supply of Ca^{2+} and increasing availability of some plant nutrients like P. Furthermore, increase in grain yield with the application of lime is ascribed to its favorable effect on the chemical, physical, and microbial properties of the soil. Numerous authors (Scott et al., 1999; Farhoodi and Coventry, 2008) reported that application of lime brings about several chemical and biological changes in the soil, which is beneficial to improve crop yields in acid soils these of our experiment with lime better grain yield than un-limed. In the present study, the better grain yield realized from the calcitic lime application during the first year indicates a fast dissolution reaction and high acid neutralization capacity of calcite lime. Similar behavior and performance were reported by other researchers about the fast dissolution and high reactivity of calcite (Hartwig and Loeppert, 1992), as well as its high effect (Bailey et al., 1989), and high solubility in acid (Merry et al., 1995).

Table 2. Result main effect of lime and different source of phosphorous fertilizer on Faba bean yield at Gozamen District

Treatment	2016				2017				Combined			
	Straw Yield Kg ha-1		Grain yield Kg ha-1		Straw Yield Kg ha-1		Grain yield Kg ha-1		Straw Yield Kg ha-1		Grain yield Kg ha-1	
	Un-lime	lime	Un-lime	lime	Un-lime	lime	Un-lime	lime	Un-lime	lime	Un-lime	lime
Control	2203	2100	965	901	3701	5059	1000	1586	1608	1648	864	738
2/3 GPAPR	2920	3039	1365	1425	4735	5842	2227	2835	2166	2154	1168	1080
Full GPAPR	2997	3100	1427	1431	4927	5830	2243	2597	2456	2338	1229	1108
2/3 MOHP	2478	2456	1141	1114	4726	4897	2147	2271	1692	1878	885	1087
Full MOHP	2365	2911	1075	1387	4590	5048	2162	2395	1986	2272	1027	1326
2/3 NAFAKA	2808	2600	1319	1120	4303	5674	2006	2709	2114	2024	1237	1071
Full NAFAKA	1955	3164	892	1500	4752	5301	2142	2462	2185	1622	1200	1352
Rec. NPSZnB	3855	3156	1840	1479	5680	6026	2585	2782	2222	2802	1152	915
CV %	14.2	17	17.4	19.5	13	14.3	14.6	18.3	13.7	19.8	17	34.6
LSD 5%	639.2	NS	362.7	NS	NS	NS	NS	NS	NS	NS	NS	NS

Soil Chemical Properties

Generally, the trend of the result indicated that liming increased soil pH and available P and reduced exchangeable acidity (Table 3). Essentially amelioration of soil acidity comprises detoxification of Al and Mn activity with the aid of lime amendment. Detoxification of Al can be achieved by increasing soil pH which in turn certainly results in a decrease in Al solubility thereby minimizes its toxic effect on plants. These findings are in agreement with those of Anetor and Akinrinde (2006) who reported increased pH and available P while lime was applied which in turn reduced P fixation. In addition, the same study revealed that lime combined with phosphorous fertilizer increased available P in Nigeria. Kisinyo et al. (2012) reported that positive effects on soil pH and available P in acid soil of Western Kenya, with the application of lime and P fertilizer in combination. The exchangeable acidity decreased from 0.49-0.91 Meq/100gm. These results compare well those of Busari et al. (2005) and White et al (2006) indicated that lime improves soil physical condition, increase soil pH, availability of nutrient, and decrease aluminum, Fe and other micronutrient toxicity.

Table 3. Lime and phosphorus residual effect on some soil chemical property of Gozamen District

Treatment	Without lime						lime					
	pH	P/PPm	OC%	OM%	Exch Acidity meq/100 gm	Exch Al meq/100 gm	pH	P/PPm	OC%	OM %	Exch Acidity Meq/100gm	Exch Al meq/100
Control	5.1	8.29	1.32	2.28	0.77	0.09	5.0	6.9	1.63	2.80	0.73	0.00
2/3 GPAPR	5.4	8.17	1.29	2.23	1.13	0.00	6.1	10.9	1.58	2.70	0.72	0.00
Full GPAPR	5.4	11.60	1.42	2.44	0.66	0.10	6.3	12	1.68	2.80	0.71	0.05
2/3 MOHP	5.5	7.12	1.53	2.64	0.89	0.00	6.1	9.3	1.61	2.80	0.66	0.06
Full MOHP	5.4	6.24	1.35	2.27	1.04	0.00	6.1	9.2	1.70	2.90	0.91	0.02
2/3 NAFAKA	5.6	11.6	1.70	2.93	0.86	0.00	6.0	10.2	1.55	2.70	0.59	0.00
Full NAFAKA	5.7	7.14	1.63	2.81	0.21	0.00	6.5	10.9	1.68	2.90	0.60	0.00
Rec. NPSZnB	5.6	6	1.46	2.51	0.65	0.00	5.7	7.1	1.57	2.70	1.05	0.08

Note: P=Phosphorus, OC=Organic Carbon, OM=Organic Matter

Economic Feasibility of liming and different P sources/rates

Partial budget analysis of the combination of lime with different phosphorus fertilizers was presented in Table 4. The net benefit of ETB 14781.5 ha^{-1} and marginal rate return of 895.1 % was obtained from a combination of 287 kg ha^{-1} NAFAKA plus lime for faba bean production. Similarly, net benefit 21657.5 ETB ha^{-1} and the marginal rate return of 92.7 % were generated from the sole use of 191 kg NAFAKA phosphorus fertilizer. Therefore, the combination of 287 kg NAFAKA ha^{-1} with lime or sole use of 191 kg ha^{-1} NAFAKA phosphorus fertilizer was economically feasible for barley production in Gozamene area.

Table 4. Partial budget analysis of lime and different phosphorus sources for faba bean

Treatment With lime	TVC (ETB^{-1})	GY (kg^{-1})	AdY(kg^{-1})	STY (kg^{-1})	AdSTY (kg^{-1})	GB (ETBha-1)	NB (ETBha-1)	MRR (%)
Control	478.3	738	664.2	1648	1483.2	16095.6	15617.3	
2/3 GPAPR	4987.3	1080	972	2154	1938.6	23538	18550.7	238.5
Full GPAPR	4996.9	1352	1216.8	2338	2104.2	28873.8	23876.9	D
2/3 MOHP	3581.7	1087	978.3	1878	1690.2	23212.8	19631.1	831.6
Full MOHP	4388.4	1326	1193.4	2272	2044.8	28299.6	23911.2	718.7
2/3 NAFAKA	3744.4	1071	963.9	2024	1821.6	23027.4	19283	D
Full NAFAKA	4957.5	915	823.5	1622	1459.8	19739	14781.5	895.1
Rec. NPSZnB	3359.1	1178	1060.2	2802	2521.8	25846.2	22487.1	D

Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (ETB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and ETB=Ethiopian Birr.

Table 5. Partial budget analysis of different phosphorus sources for faba bean

Treatment Without lime	TVC (ETB^{-1})	GY (kg^{-1})	AdY(kg^{-1})	STY (kg^{-1})	AdSTY (kg^{-1})	GB (ETBha-1)	NB (ETBha-1)	MRR (%)
Control	0	864	777.6	1447.2	1608	18715.2	18715.2	0
2/3 GPAPR	4509	1168	1051.2	1949.4	2166	25292.4	20783.4	D
Full GPAPR	4518.6	1229	1093.1	2210.4	2456	26504.2	21985.6	26.6
2/3 MOHP	3103.4	885	796.5	1522.8	1692	19215	16111.6	D
Full MOHP	3910.1	1027	934.3	1787.4	1986	22540.6	18630.5	D
2/3 NAFAKA	3266.1	1152	1036.8	1902.6	2114	24923.6	21657.5	92.7
Full NAFAKA	4479.2	1200	1080	1966.5	2185	25874	21394.8	21.7
Rec. NPSZnB	2880.8	1237	1113.3	1999.8	2222	26714.6	23833.8	84.7

Note: AGY (kg/ha)=Adjusted grain yield, GB (GY)=Gross benefit, TVC (EB/ha)=Total variable costs, NB (Birr/ha)=Net benefit and MRR (%)=Marginal rate of return, D=Dominated treatment and EB=Ethiopian Birr.

Conclusions and Recommendation

The objective was to assess the effect of different sources of phosphorus fertilizer for faba bean production with acidic soil at Gozamen District in 2016-2017. However, the interaction effect of lime and P fertilizer application on grain yield of faba bean was significant only during the first year. But the combined analysis of variance over years showed no significance. The results of soil increased soil pH and available P, while exchangeable acidity and Al^{3+} had decreased by the application of 1/4th recommended lime based on exchangeable acidity. The application of 287 and 191 kg h^{-1} NAFAkA phosphorus source fertilizer both limed and un-limed were recommended for the study location and similar agro-ecologies in acidic soil of Ethiopia.

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