World Journal of Agricultural Sciences 17 (5): 460-468, 2021
ISSN 1817-3047

DOI: 10.5829/idosi.wjas.2021.460.468

Response of Faba Bean (*Vicia faba* L.) for Combined Uses of Lime with Varied Phosphatic Fertilizers on Acidic Nitisols of Welmera District, Ethiopia

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Abstract: The world fertilizer utilization trained showed that with the current fertilizer the demand of phosphatic fertilizers market their main reserve of raw material or apatite become depleted within the coming five decades consequently it's critical to use this non-renewable resource with intensive efficiency by minimizing losses in all aspects are mandatory. with this main objective study is conducted on the response of faba bean crop (*Vicia faba* L.) for combined uses of different phosphorus fertilizer sources with different lime application rates on acidic Nitisol of Welmera district in two experimental sites in 2017/18 cropping season. Four different phosphorus sources with two application rate and two lime rates was evaluated with factorial randomized complete block design. From collected plant growth performance yield and soil data, it was possible to obtain statistically significant differences accordingly, use of NPSB blended fertilizer sources with lime can gave better yield and other related crop growth performance advantage. Other phosphorus sources like MOHP and PARP sources can give comparative yield advantage with superior once at 46 kg P_2O_5 ha^{-1} application rate which makes them more preferable compared to their cheap production cost and availabilities on the other hand's application of lime also improve the productivity of acidic Nitisol of Welmera which improves yields of faba bean on the study site.

Key words: Nitisol · *Vicia faba* L. · Lime · Acid Soil · Phosphorus Sources · PARP · MOHP · NPSB

INTRODUCTION

Phosphorus (P) is one of the major nutrients required to sustain life on earth, compounds which contains it are vital in metabolism, membranes, structural support, genetic components and it involved in photosynthesis process. P is abundant in the lithosphere, it is one of the most unavailable and inaccessible essential macro-nutrients required by plants. It can be either form insoluble complexes with iron (Fe), aluminum (Al) or calcium (Ca) be adsorbed to soil particles, or be bound to organic compounds that must be enzymatically cleaved before uptake [1]. However, large areas of soil used for agriculture across the world are deficient in plant-available forms of phosphate, which can limit agricultural production [2]. Which makes the problem more complicated in acidic soil due to the dominancy of Fe and Al ions which commonly involved in P fixation resulted unavailability to the crop uses. Soil acidity is one of the major constraints for the production and productivity of crops in high rainfall areas of Ethiopia. According to EthioSIS [3] this soil is estimated to be covering more than 43% of the arable land of the country.

The productivity of food legumes is constrained by low soil pH and the consequent low P availability. Acidic Nitisols are of wide occurrence in the highlands of Ethiopia where the rain fall intensity is high and the land has been under cultivation for many years [4]. These soils, by and large, have pH values of less than 5.5, there by resulting in low faba bean yields in comparison to other potential areas of the country. Phosphorus-based fertilizers are used routinely in agricultural systems to overcome deffciency of soil P. Some 17.5 million tons of P is processed annually from world reserves of rock phosphates, of which approximately 85% is used in the production of fertilizers [5]. However, reserves of rock-P

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are finite with an estimated depletion of quality sources expected to occur within the next 50–80 years [6]. Phosphate rock (*apatite*) is the natural and economical source of P for production of phosphate fertilizers and has become the subject of investigation in the recent years as a reasonably effective source of P fertilization to crops under acidic and alkaline soil environment, [7]. Many studies have been performed in order to evaluate the efficiency of phosphate rock treated with different acidulates at varying degrees of acidulation to excess available and soluble P in low available P soils [5]. Consequently, evaluating alternative sources of P fertilizers beyond the water-soluble ones is critical to increase the efficiency of fertilizer uses and minimize the loss of P nutrients resulted from excessive fixation resulted from acidic soils

Furthermore, to achieve optimal faba bean production on acid soils, it is necessary to apply sufficient lime to eliminate toxicities of Al and Mn, supply adequate levels of Ca and Mg, create conditions which maximize the availability and uptake of the essential nutrients majorly P and the performance of the rhizobium-legume association and create conditions which control soil pathogens [8]. Addition of organic sources like manure and compost to acid soils is potentially a practicable low-input strategy for increasing soil pH, decreasing concentrations of Al and reducing lime requirements [9]. Integrated uses of partly acidulated phosphatic fertilizer products also serve as one of amendment mechanism of such soil impacts.

MATERIALS AND METHODS

Study Area: The field experiment was conducted in Wolmera district two locations at Holeta Agricultural Research Center Farm (OnS) and "*Rob Gebeya*" farmer's field (OnF), in Welmera district of the central Ethiopian highland, to the west of Addis Ababa (Figure 1). Geographically located at DMS 9°.3'.34.4"N and 38°.30'.41"E with 2373 m altitude and *Rob Gebeya* on-farm at 9°.7'.53.5"N latitude and 38°.26'.25.2"E longitude with 2604m altitude, respectively in Welmera district of Oromia regional state.

Climate: The recent five years (from 2013 to 2017 inclusive) weather records of Holeta Agricultural Research Center showed that a mean annual air temperature of 14.6°C that varies from 5.8°C minimum monthly average up to 23.4°C monthly mean maximum temperature. The absolute monthly mean maximum of 28.8°C and minimum of -0.6°C occurred in Jan and March 2013 respectively. The average sunshine hours are 6.8 hours/day in a year and this varies between 2.7 hours/day in July and 9.1 hours/day in November. Holeta or Welmera area receives an average total rainfall of 919.4 mm annually, whereas at the study year (2017) 1071.6 mm rain was registered (Figure 2). This is spread over all months except December and ranges from the lowest of 0 mm in December to the highest of 311 mm in August 2017.

Field experiment was conducted to determine the effects of using different Phosphorus fertilizer sources with lime on faba bean crop by using factorial RCB design with three replications, which have three experimental factors which contains four different type of phosphorus sources i.e. PARP, MOHP, NPSB and NAFAKA blended fertilizer; two Phosphorus fertilizer rates (23 kg P_2O_5 ha^{-1} and 46 kg P_2O_5 ha^{-1}) (Table 1) and two lime rates (with and without lime it was computed from the soil exchangeable acidity result for each study site). Composition of Phosphorus sources include:

- PARP (Granular partly acidulated rock phosphate): have P_2O_5= 49% (20% soluble in mineral acid, 18% soluble in water & neutral ammonium citrate, 11% soluble in water), S=7%, B= 0.6% and Zn= 2%.
- MOHP (Organic hyper-phosphate): with P_2O_5 28% and CaO 36%
- NPSB (Formula II Blend fertilizer): N= 18.1%, P_2O_5= 36.1%, S = 6.7% + B= 0.71%.
- NAFAKA plus: N= 9%, P_2O_5 =16%, K_2O = 16%, CaO= 25%, S= 5% MgO= 2%, Zn= 0.5% & B= 0.1%.

In all treatments major essential nutrients Nitrogen, Potassium, Sulfur and Boron are kept in the same rate for all treatments by using fertilizer sources like: Urea $CO(NH_2)_2$ 46% N, Muriate of potash (MOP) KCl 60% K_2O, Ammonium sulphate $(NH_4)_2SO_4$ 21% N and 24% S; and Borax ($Na_2B_4O_7.10H_2O$) 11% B respectively used as other sources of essential nutrients. From previous studies recommended phosphorus and nitrogen fertilizer rate for faba bean production on Nitisol of Wolmera district is 46 kg P_2O_5 ha^{-1} and starter 23 kg N ha^{-1} respectively, Other major essential nutrient (except N and P) application was determined according to the recommended rate of NPSB based on P content depending on EthioSIS fertilizer recommendation [3]. i.e. NPSB with 48 kg P_2O_5 ha^{-1} obtained from 127 kg ha^{-1} (114 g $plot^{-1}$) NPSB application. 127 kg ha^{-1} NPSB containsP_2O_5=46 kg ha^{-1}; S=8.5 kg ha^{-1}; B= 0.76 kg ha^{-1} so other P fertilizer types was fixed accordingly.

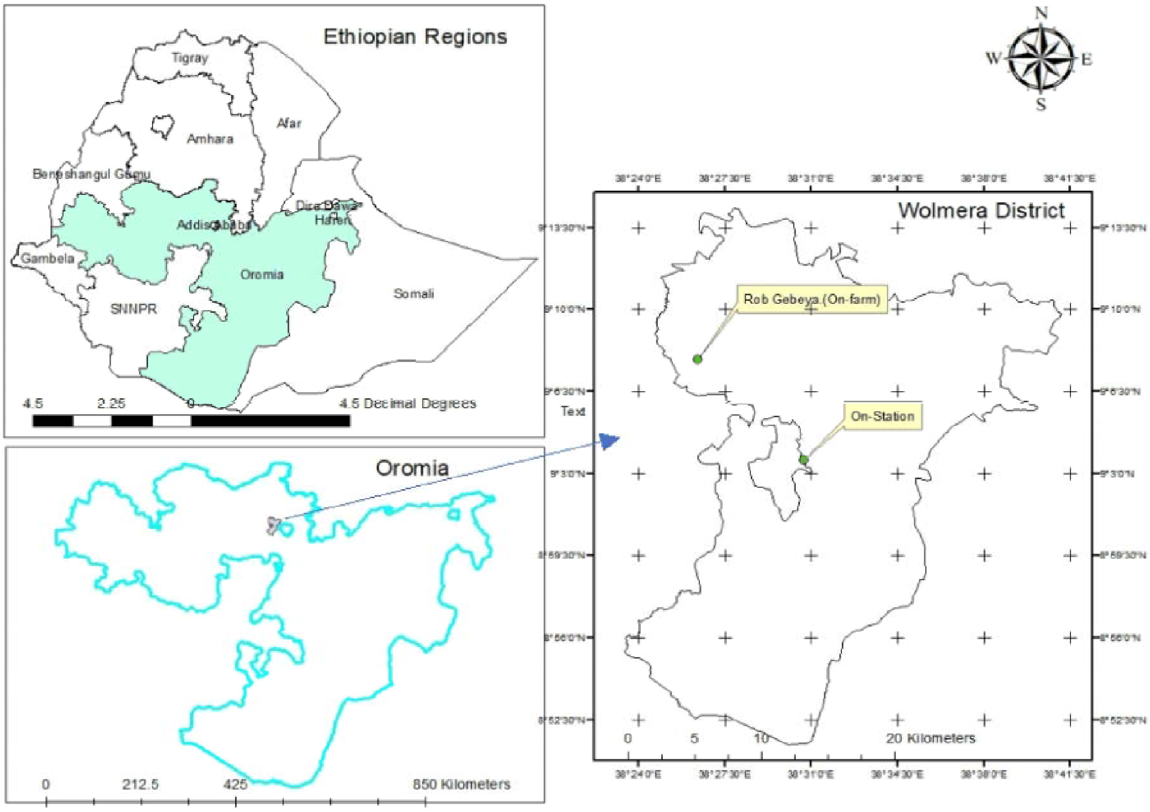

Fig. 1: Geospatial location of study site in Wolmera district of Oromia regional state, Ethiopia

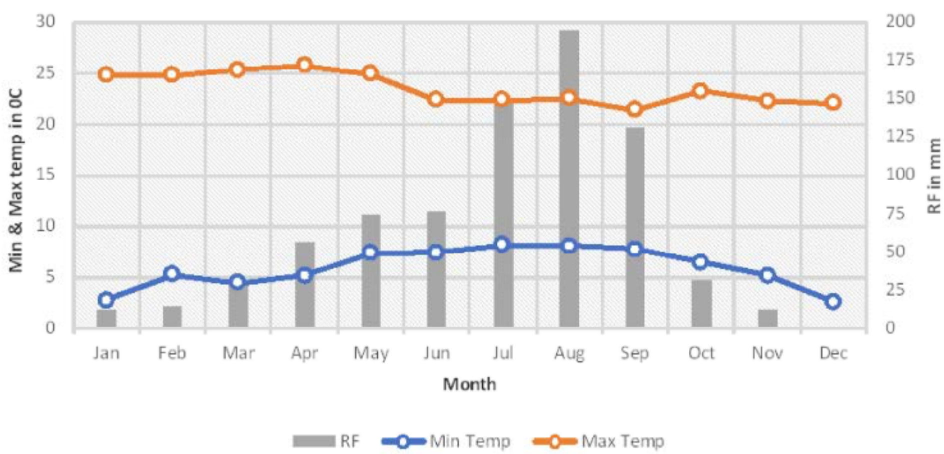

Fig. 2: Five years mean climatic data for Holeta agricultural research center taken from center weather station record data (2013-2017)

Lime Application: Amount of lime required to reclaim acidic soils of the study area is determined by using exchangeable acidity method [10] described in the following equation.

$$LR, CaCO3\left(in\frac{kg}{ha}\right) = \frac{cmol\frac{EA}{kg}of\ soil\ *1.15m\ *10000\text{m}^2 * B.D\left(\frac{Mg}{ma}\right)*1000}{2000} * factor(2\ for\ pulse\ crops)$$

Table 1: Fertilizer treatment application of different Phosphorus source of fertilizer and other essential nutrients

	Phosphorus sources (kg/ha)				Other Nutrient sources(kg/ha)			
Treatments (Ferz'r)	PARP	MOHP	NPSB	NAFKA	$CO(NH_2)_2$	NH_4SO_4	Borax	Kcl
1. Control	-	-	-	-	-	-	-	-
2. PARP (23 P_2O_5)	46.95				32.6	21.79	8.18	14.3
3. PARP (46 P_2O_5)	93.9				38.9	8.11	8.18	28.7
4. MOHP (23 P_2O_5)		82.15			26.4	35.49	8.18	14.3
5. MOHP (46 P_2O_5)		164.3			26.4	35.49	8.18	28.7
6. NPSB (23 P_2O_5)			64		9.4	17.59		
7. NPSB (46 P_2O_5)			127		-			
8. NAFKA (23 P_2O_5)				143	22.0			
9. NAFKA (46 P_2O_5)				286	-			

where: Control treatment was included for different comparisons i.e. trt. # 1 all of those treatments were done under limed and un-limed condition

Table 2: Determination of lime rate using exchangeable acidity for hectare and plot areas of on station and on farm study sites

Location	pH	Ex. A	$CaCO_3$	LR *2	In gram	Kg/block
On-station	5.04	0.25	206.25	412.5	113437.5	11.344
RG. On-farm	4.84	1.05	866.25	1732.5	476437.5	47.644

where: 0.15 m is the plow depth; 10^4 m^2 is area for 1 hectare of land; B.D is bulk density of the soil multiplied by 1000 to convert Mg to kg. Assuming that one mole of EA (exchangeable acidity) would be neutralized by equivalent mole of $CaCO_3$ (milli-equivalent weight of $CaCO_3$is 50 mg i.e. 50 mg of $CaCO_3$ required per 100 g of soil or 500 mg1 kg^{-1} of soil i.e. 500 mg = 0.5g =1/2g to convert g to kg 1/2g = 0.0005 kg = 1/2000).Accordingly, the lime rate for both experimental sites was 412 and 1732.5 kg per hectare for on station and on farm sites respectively (Table 2).

All fertilizer treatments were applied with band application method at planting it was done at 11^{th} July 2017 by using row planting method with spacing of 40 cm and 10 cm between rows and plants on plot area6 m^2 (2m x 3m.), "*Dosha*" faba bean variety was used by treating with "*FB-1035"* faba bean rhizobia strain. The two border sides rows were rejected during data collection in each experimental unit and the inner 4 rows were taken for all kinds of agronomic data collection. Spacing between plots and blocks were 0.5m and 1m respectively. The testing site was geo-referenced to generate area specific micro nutrient deficiency information and to determine the micro nutrient requirements.

Data Collection

Soil Sampling and Analysis: Random soil samples were taken at surface (0-20 cm depth) to assess the physicochemical properties and its fertility dynamics of the study site soils during the field experiment, fifteen samples were collected before treatment application from each study locations and bulked in to two composites to characterize the experimental site. Finally, after harvesting soil samples were collected treatment wise (stratified soil sample collection) to assess the residual effect of the treatments; to determine the crop nutrient use efficiency and other related parameters. Texture (Hydrometer method), BD (core sampling), pH (1:1.2.5 H_2O), CEC (ammonium acetate), total N (Kjeldhal Bremner and Mulvancy), available P (Bray II), basic cations (ammonium acetate), exchangeable acidity (Van reeuwijk, L.p 1N KCl leaching titration), organic carbon (Walkley-Black chromic acid wet oxidation method), sulphate-sulfur (turbidimetric method) and boron were by using dilute hydrochloric acid method which is more suitable for acidic soil types [11].

Agronomic Data: Plant height number of branches per plant number of seeds per pod was taken by selecting 5 representative plants and computes their average values. Date of flowering and maturity was recorded while more than 75 % of plant population with plots attains the required growth stage.

Yield and Yield Components: Dry above ground biomass AGB and grain yield GY were collected from each experimental unit independently. Grain quality data like thousand seed weight and hectoliter weight was taken.

Plant Biomass was taken by using sack in plot base during harvesting from the middle experimental rows of faba bean as fresh total biomass and after air drying at thrashing time takes independently then the final data was considered as a total dry biomass for each experimental unit.

Grain Yield (GY): After threshing the harvested crop, grain yield obtained from each experimental plot were taken by nylon bag independently and weighted their mass with their moisture % age by using moisture tester finally the grain yield was converted in to kg ha^{-1} unit then all the data were readjusted to 12 % common grain moisture level.

Statistical Analysis: Agronomic data, grain quality parameters and soil data were subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS version-9.0) to evaluate the effects of different P fertilizer source with different lime and fertilizer application rates. Results were presented as means with Least Significance Difference (LSD) at 5% probability level [12]. Over location combined data of some parameters was done since largest standard error SE to least SE ratio was below 3 which indicates its homogeneity across experimental locations [13].

RESULTS AND DISCUSSION

Soil Physical Properties: Texture or soil particle size distribution analysis results for study site were characterized as "Clay" for Holeta on station and "Clay loam" textural class for Rob Gebeya on-farm. Both study sites soil physical properties were categorized under heavy texture class, much influenced by their higher amount of clay particles (Figure 3). Thus, organic fertilizer application influences its response to physical properties. It also has several influences on the P fixation, nutrient holding capacity, buffering capacity and other chemical properties related to productivity of such soils [14]. Whereas the bulk density of both studies areas was 1.14 and 1.12 gm cm^{-3} respectively.

Soil Chemical Properties: pH for On-station experimental site soil before treatment application was 5.04 which is categorized under 'strongly acidic soil property according to USDA/NRCS rating [15], while for the Rob Gebeya on-farm (OnF), the average pH was 4.84which is virtually the same rating category with the Holeta on station (OnS) experimental site according to their soil pH results which used as primary criteria to select study location in specific district.

Exchangeable Acidity: Mean exchangeable acidity (Al^{3+} and H^{+}) results for both locations soil samples were 0.25 and 1.05Meq 100^{-1} gram of soil for OnS and OnF site respectively (Table 3). As reported by several authors soil pH value with <5.2 usually have problems of Al toxicity or acidification, but they can be improved by amendment practices like application of lime, compost or organic manure [16]. Up on liming [17] reported decreases of Al^{+3} in the soil solution as well as in the exchangeable complex which creates conducive soil environment for potential crop production and soil fertility enhancement as it controls the major cations exchange on acidic soil which are limiting for crop production in such types of soil.

Available P (AP in ppm) For the OnS and OnF trial sites available phosphorus level was recorded as 8.29 ppm and 14.9 ppm respectively. The level of AP in both study site was categorized as medium P level since their level is between 8-15 ppm according to [18] as a major yield limiting nutrient and the P sorption limitation of acidic soil, managing phosphorus to the optimal level and quality of application which fits the crop requirement is quite necessary in acidic soil management practices.

Organic Carbon (OC %) for OnS it was1.48%, while OnF) OC content was 2.3% on average. When OC converted to organic matter the percentage of total soil OM becomes 2.52 % and 3.91% for the two experimental sites respectively, these results was categorized under low level of OC or OM according to Brook rating [19]. The humic and fulvic acids would seem to have the highest chemical activity, but the particulate organic carbon has the highest capacity to maintain the stability of larger soil aggregates and other physicochemical property implications.

Total Nitrogen: OnS and OnF study sites had total N result 0.125 % and 0.227% respectively which are categorized under low and medium total nitrogen level according to Bruce and Rayment rating [20], which is major yield limiting and major indicator for soil fertility in most cases.

Cation Exchange Capacity (CEC): Mean result for the two experimental sites was recorded as 20.25 and 23.84 Meq100^{-1}g of soil for OnS and OnF respectively; they are categorized under moderate level of CEC according [21] rating which is most common values for heavy texture soils. These can strongly associate with their pH buffering and most other soil chemical properties related to efficiency of acid soil amendment methods and soil fertility management practices.

Application of phosphorus fertilizer was significantly improving all considered para meters in both experimental sites compared to the control or negative treatment.

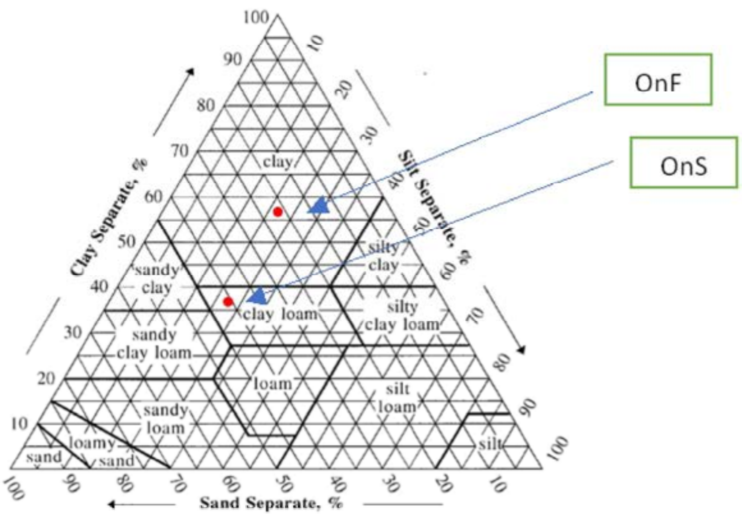

Fig. 3: Soil textural property of the experimental sites at Holeta on station and Rob Gebeya on farm

Table 3: Preliminary soil test result for Holeta on station and Rob Gebeya on farm experimental site at Wolmera districts

Loc'n	Clay %	Silt %	Sand %	pH	Ex.A (Meq/ 100g)	TN %	CEC(Meq/100g)	P ppm	Mg (Meq/ 100g)	Ca (Meq/ 100g)	Na (Meq/ 100g)	OC %	OM %
On-station	36.25	21.88	41.88	5.04	0.25	0.123	20.25	8.294	7.471	8.953	0.06	1.48	2.516
On-farm	56.25	21.25	22.5	4.85	1.05	0.227	23.84	13.973	3.326	2.089	0.14	2.3	3.91

On the other hands most of the parameter were although non-significantly affected by different sources of phosphorus fertilizer rate and lime applications, application of different phosphorus sources significantly affects number of pods per plant at Holeta on station; above ground dry biomass and grain yield at Rob Gebeya. Accordingly using NPSB blended fertilizer can gave 12.6 pod per plant which is relatively better than other sources similarly MOHP and PARP sources of phosphorus can also gave statistically comparative advantage with this fertilizer source entry (Table 4) like study in Welmera [4] also indicated that application of phosphorus fertilizer at optimal rate improve faba bean pod number per plant.

Application of different sources of phosphorus fertilizer also affect the grain and biomass yields at Rob Gebeya locations accordingly relatively highest yield advantage it can gave 8950.9 and 2600 kg ha^{-1} biomass and grain yield respectively which is 28.1 and 36.4% yield advantage over the control were obtained from NPSB sources of phosphorus fertilizer at Rob Gebeya experimental site, in both cases MOHP and PARP sources can attain statistically comparative yield advantages respectively with NPSB blended fertilizer which is appreciable compared to the high production costs of high grade water soluble phosphorus fertilizers similarly other study [22] also showed their benefit as Partial acidulation of RP (PARP) is a cost-effective method to improve the P supplying ability of indigenous RPs that have inherently low solubility. In PARP, RP is acidulated with lesser quantity sulfuric acid and phosphoric acids than the quantities of acid needed to produce superphosphate or high-grade water soluble phosphatic fertilizers [23]. Although, the effectiveness of this method depends upon several factors, there is a general consensus that PARPs prepared from highly reactive indigenous RPs and acidulated to the level where 40% or more P is present as water soluble P, could be as effective as superphosphate fertilizers [22, 24, 25].Other study also indicated that [4, 26, 27] efficient use of phosphorus fertilizer for faba bean production improve grain and biomass yields with other growth performance which is most likely related to the intensive root growth from phosphorus which in turn improve the water and nutrient uses of faba bean in performing healthy crop metabolic process in their growth and productivity.

Although considered application rate of phosphorus fertilizer do not have statistically significant difference each other on considered parameters all of the parameters are found to be better at phosphorus application rate of 46 kg $P_2O_5ha^{-1}$other study also demonstrated that faba bean yield response to P fertilization is dependent on the residual fertility level of nutrients in the soil [28, 29].

Table 4: ANOVA results to response of faba bean for different phosphorus sources, rate and application of lime in Holeta on station and Rob Gebeya experimental sites

	Plant height (cm)		No. of pod/plant		Biomass kg ha^{-1}		Grain yield kg ha^{-1}	
Treatment	HARC	R.G	HARC	R.G	HARC	R.G	HARC	R.G
1	93.5	86.6	11.3AB	7.6	7174.7	8177.4AB	2150.3	2278.4AB
2	97.7	87.4	11.8AB	7.5	7552.3	8472.1AB	2209.7	2367.6AB
3	98.4	87.1	12.6A	8.4	8081.0	8950.9A	2345.1	2600.3A
4	97.3	84.9	9.4 B	7.3	8005.5	7919.5B	2394.6	2146.3B
Lsd	ns	ns	2.65	ns	ns	1003.9	ns	361.8
Different P sources include 1. PARP, 2. MOHP 3. NPSB and 4. NAFKA blend fertilizers								
1	95.61	86.17	11.16	7.4	7382.41	8251	2172.48	2263.9
2	97.78	86.8	11.4	7.9	8024.35	8508.9	2377.37	2432.4
Lsd	ns	ns	ns	ns	ns	ns	ns	ns
Phosphorus rate 1. 23 kg $P_2O_5ha^{-1}$and 2. 46 kg $P_2O_5ha^{-1}$								
1	97.38	87.6	11.43	7.8	8496.38A	8527	2562.6A	2393.7
2	96.01	85.4	11.13	7.6	6910.39B	8232.6	1987.3B	2302.6
Con'l	92.13	75.4	8.67	6.1	6543.5	6988.7	1805.4	1905
Lsd	ns	ns	ns	ns	742	ns	280.9	ns
CV (%)	9.01	14.23	28.1	33.8	16.3	14.4	20.95	18.5

Lime application rate 1. With lime and 2. Without lime application

where: The result includes three factors of 1. Phosphorus source, 2. P. rate and 3. lime application in to study sites HARC:(Holeta on station) and RG: Rob Gebeya on farm locations

Application of lime significantly improve the biomass and grain yields of faba bean at Holeta on-station accordingly it is possible to achieve 23 and 29 % biomass and grain yield advantage over the un-limed treatments respectively. furthermore, its application correspondingly can improve all of considered parameters of faba bean in both experimental sites. other studies also confirmed that lime application on acidic soils improve those traits of crop performances through enhancing soil fertility by modify its pH and improve phosphorus availability for crop uses on acidic soil, when soil pH is increased phosphorus adsorption is expected to decrease as a result of the increase in hydroxyl competition for the adsorption sites and an increase in negative surface charge. However, in the presence of exchangeable aluminum an increase in pH may cause the formation of aluminum hydrous oxides with high surface area which have a high affinity for phosphorus [30]. The effect of increase in pH on P adsorption depends on the balance between increasing hydroxyl competition for adsorbing sites and the formation of new adsorbing sites and in these soils the two effects must be approximatelyequal.in soils with low contents of exchangeable aluminum (A1 < 1.5meq l00g^{-1}) lime application decreased P adsorption [31, 32]. In soils with a medium content of exchangeable aluminum (A1 < 2.7 meq l00g^{-1}) P adsorption was not affected by liming [33]. In a soil with a high content of exchangeable aluminum (6 meq 100g^{-1}), liming increased P adsorption up to a pH of about 6.5 [34].

CONCLUSION

Field experiment were conducted in Welmera district of Oromia regional state of Ethiopia in to experimental locations to determine the response of faba bean crop for application of different phosphorus fertilizer sources, application rate and use of lime on acidic Nitisols of Welmera district which combined with factorial RCBD design in to three replications. Improved faba bean verities with appropriate rhizobia stain were used for the experiment at Holeta on station and Rob Gebeya on farm sites. All major crop growth performance and yield data were collected with soil data of the trial sites.

From statistical analysis of variance application of different phosphorus sources and lime can gave statistically significant difference. From those results use of NPSB phosphorus sources can gave better yield and other related advantage over other sources as an alternative other sources of phosphorus fertilizers like MOHP and PARP which have less production and market costs can gave statistically comparative advantage with the superior once which is more advantages in terms economic feasibility, environmental safety and sustainable soil fertility enhancement. Considered application rate of phosphorus can't show statistically significant difference although 46 kg P_2O_5 ha^{-1} rate can gave better performance on all parameters which is acceptable rate from the previous studies in the same location and soil type.

On the other hand, application of lime also improves the grain yield and biomass yields of faba bean. Accordingly, it's possible to have 23 and 29% biomass and grain yield advantage over the un limed set of treatments respectively which is varied depending on the soil acidity attributes (like soil pH, Exchangeable acidity, Percent acid saturation PAS etc.) of study area and lime rates which are determined by using different method in this case exchangeable acidity method was used to compute the required amount of lime and multiplied by factor 2 which is used for pulse crops or less soil acid tolerant cops which is effective in acidic Nitisol of Welmera district and applicable to other similar agro-ecologies with more intense study which incorporate organic amendment options.

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