Effects of Phosphorus Fertilizer Rates on Soil Properties, Nodulation and Yield of Faba Bean (Vicia faba L.) Varieties in Lemu Bilbilo District of Arsi Zone, South Eastern Ethiopia

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Abstract
A field experiment was conducted on farmer's field during the 2017 main cropping season at Lemu Bilbilo with the objectives to determine the response of faba bean varieties to different rates of phosphorus fertilizer on nodulation and yield components of faba bean and the interaction effect of both phosphorus and faba bean varieties on yield and yield components of faba bean. The treatments include three faba bean varieties (Tumsa, Gebelcho and Dosha) and five phosphorus levels (0, 10, 20, 30 and 40 kg P ha^{-1}) from TSP. The experiment was laid out in a randomized complete blocked design with factorial arrangement of 3 x 5 =15 treatment combinations with three replications. Significantly ($P< 0.05$) higher total number of nodule, effective nodules and non-effective nodules were recorded from Tumsa variety. Number of nodules per plant, and biomass yield were significantly affected by main effect of varieties. Higher total number of nodules per plant (63), number of non-effective nodules per plant (7.82) and nodule volume per plant (1.57 cm^3) were obtained from application of 30 kg p ha^{-1}. Higher biomass yield (14158 kg ha^{-1}) and grain yield (6323 kg ha^{-1}) were obtained from application of 40 kg P ha $^{-1}$. Applications of different rates of P highly significantly ($P<0.001$) influenced on faba bean agronomic phosphorus use efficiency. Most of the parameters studied were positively correlated to biomass and grain yield of faba bean. Therefore, it can be concluded that application of 30 kg ha^{-1} of P with faba bean varies was proved to be productive and superior both in grain yield as well as economic advantage and might be recommended for Lemu Bilbilo area. Further study should be repeated both over locations and years in order to give full recommendation for practical application.
Keywords: Faba bean, Phosphorus rates, available P, soil pH, basic cations, nodules
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1. INTRODUCTION

Faba bean is the most important pulse crop in Ethiopia, occupying about 34% of the total land area under pulses (CSA, 2007). It is one of the major winter sown legume crops grown in the world and has considerable importance as low-cost food rich in proteins and carbohydrates **(**Sepetoğlu, 2002**)**. It ranked first among cool season food legume based on hectarage, production, and foreign exchange earnings (CSA, 2016). Faba bean has four main functions in agro-ecosystems: providing food and feed that is rich in protein; increasing soil fertility by supplying N to agroeco systems by symbiotic N_2 fixation with Rhizobium; diversifying the crop system to reduce constraints on growth and yield by the other crops in the rotation; and reducing fossil energy consumption for crop production **(**Nikfarjam and Aminpanah, 2015).

Faba bean production has been increased in area throughout the different parts of Ethiopia. It is grown from 1300 to 3800 m altitude, but mostly at 2000 to 2500 m (Getachew and Chilot, 2009). However, the average national productivity of faba bean is 2.1 t ha^{-1} but, is low as compared to the world top producers (CSA, 2017).

Several abiotic and biotic factors contributed to this low productivity (Asfaw *et al.,* 1997). (Asfaw *et al.* 1997) and ICARDA (1989) reported the major ones are poor crop management practices, susceptibility to environmental stresses, pests and diseases, and the inherently low yield potential of the prevalent cultivars due to poor soil fertility, acidity of the soil in high rain fall areas and low existence of effective indigenous rhizobia population are other responsible factors (Carter *et al*., 1998). However, improved varieties have the capacity to tremendously increase productivity of faba bean, if used along with their optimum recommended inputs and management practices.

Of the major cool season grain legumes, faba bean has the highest average reliance on N_2 fixation for growth (Adak and Kibritci, 2016). The total amounts of N-fixed by faba bean are between 327-450 kg N ha^{-1} (Adak and Kibritci, 2016). Savings (up to 100–200 kg N ha^{-1}) in the amount of N fertilizer required to maximize the yield of crops grown following faba bean is possible (Jensen *et al*., 2010). The use of faba bean crop rotation had a significant effect by reducing the amount of chemical nitrogen applied to soil for crop production (Tolera *et al*., 2015). The straw of faba bean is also used as animal feed and soil fertility restorer (Habtegebriel *et al*., 2007). It is also of great importance in legume–cereal production systems, in which it is used as break crop for cereals (Amanuel *et al.,* 2000) and has the potential to enhance N and P nutrition of cereals (Rose *et al*., 2010).

Phosphorus plays a significant role in several physiological and biochemical plant activities like photosynthesis, the transformation of sugar to starch and transporting of the genetic traits (Zaki *et al*., 2012). It has positive effects on nodule formation and nitrogen fixation in legume crops and plays a vital role in the structure of nucleus and cell membrane (Sepetoğlu, 2002, Raghothama and Karthikeyan, 2005). In spite of the considerable addition of phosphorus to soil, the available amount of phosphorus for plants is usually low because its availability to plants is limited by different chemical reactions especially in high rain fall areas. Phosphorus is also one of the most important elements that are significantly affecting plant growth and metabolism. It is, along with N, a major yield-limiting nutrient in many regions of the world, legumes require high amounts of P due to the involvement of P in energy transfer rate that must take place in the nodule (Kandil *et al.,* 2013). Richards *et al.* (2011) pointed out that the increase in solubility of phosphorus in soil solution causes an increase in iron uptake by the plant which contributes in increasing nitrogen fixation by legumes then increase in protein content and seed quality. Phosphorous is involved in nodule metabolism, stimulating their growth and development (Leidi and Rodiguez, 2000; Giller, 2001). Phosphorus deficiency is one of the most widespread soil constraints in highland soils. Furthermore, Getachew *et al*. (2005) aid that acid soils could expose faba bean to greater chocolate spot infection there by reducing yield. Phosphate can readily be rendered unavailable to plant roots as it is the most immobile of the major plant nutrients.

Faba bean production in Ethiopia is limited and fails to face the increasing local consumption of seeds due to gradual decreases in its average yield (Asfaw and Kiya, 2016). It is a very important crop in the Arsi zone grown to break the monoculture wheat based farming system that always suffers from attacks by new races of rust with significant yield reductions. Low crop yields associated with predominantly nutrient-related soil constraints to crop production constitute an undoubted characteristic of subsistence cropping systems throughout Ethiopia. In Ethiopia research work regarding use of P and its role in legume growth, nodulation, N_2 fixation and grain yield and yield components is very limited. Inclusion of this crop in the crop rotation system with the application of optimum phosphorus fertilizer which is a limiting factor for the production of faba bean is crucial in the highlands like study area. Indeed, testing of the alternative technology for different varieties is very essential to assess its feasibility and ascertain the response of improved varieties to inputs of production in the region. The present study is conducted with objectives of determining the response of faba bean varieties to different rates of phosphorus fertilizer rates on nodulation and yield components of faba bean and identifying the interaction effect of different faba bean varieties to phosphorus application rates on yield and yield components of faba bean.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

Field experiment was conducted in Lemu Bilbilo district, Arsi Zone of Oromia National Regional State, Southeastern Ethiopia in 2017 main cropping season. Lemu Bilbilo lies between 7.55 ºN and 8.26 ºN latitude and 39.23ºE and 39.26 ºE longitude at an average altitude of 2780 meters above sea level. The study area is characterized by an agro-ecology of sub-humid tropics and high rainfall. As per the climate data recorded at Kulumsa Agricultural center Metrological station, Bekoji substation, eleven years mean annual rainfall of district was 964.2 mm with quasi bi-modal distribution where the mean maximum rainfall (190.6 mm) occurs in August. The mean minimum and maximum temperature of the period 2007-2017 are 3.5 and 19.8 ºC respectively. The topography of the study site is mountainous and has a gentle sloping landscape. The dominant soil of the study area is classified as Nitisols with the pH of 5.0 (Birhan, 2011, IUSS Working Group, 2014). The farming system of the study area involves mixed farming crop and animal production. The cropping system is mostly dominated by mono cropping of cereals such as, wheat (*Triticum aestvum* L.) and barley (*Hordeum vulgare* L.). Legumes faba bean (*Visia faba* L.), field pea (*Pisum sativum* L.) and linseed (*Linum usitatissumum* L.) are also grown even though the farmers are not intentionally practicing crop rotation.

2.2. Treatments, Experimental Design and Experimental procedures

Factorial combinations of three faba bean varieties (*Tumsa, Gebelcho* and Dosha) and five phosphorus levels (0, 10, 20, 30 and 40 kg P ha^{-1}) from TSP were used for the experiment. The experiment was laid out in a randomized complete blocked design with factorial arrangement of 3 x 5 combinations with three replications. The seed rate of faba bean was 200 kg ha^{-1} for each variety. Triple Super Phosphate and urea were used as source of phosphorus and nitrogen respectively.

The land was prepared by oxen plough (farmers' practice) using local maresha. Faba bean seeds were sown in row with 40 cm inter rows and 10 cm intra row spacing. Applications of different rates of phosphorus fertilizer as Triple superphosphate were done in the rows of faba bean seed once at planting. Nitrogen (18 kg N ha^{-1}) fertilizer was applied as urea uniformly at sowing in rows of faba bean and mixed to soil and improved agronomic management practices (weeding, hoeing, disease management etc.) was applied for faba bean during the growing period. The gross and net plot size of each plot were 2.6 m x 4 m (10.4 m^2) and 2.6 x 2.4 m (6.24m^2). The spacing between blocks and between plots was 1m and 0.5m respectively.

The land was prepared by oxen plough (farmers' practice) using local maresha. Lime ($CaCO_3$) was uniformly applied to experimental plots a month before planting to treat soil acidity. A high-quality limestone (98 % $CaCO_3$, 99.5 % <250 µm in diameter) was used. The amount of lime required was calculated on the basis of exchangeable acidity concentration of the site (Kamprath, 1984), assuming that one equivalent of exchangeable acidity would be neutralized by an equivalent of $CaCO_3$. The amount of lime applied was calculated on the basis of the mass of soil per 15 cm hectare-furrow-slice, soil sample density and exchangeable Al^{+3} and H^{+1} of the site. Assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of $CaCO_3$.

$$LR, CaCO_3 (kg/ha) = \frac{cmol\ EA/kg\ of\ soil * 0.15\ m * 10^4\ m^2 * BD\ (mg/m^3)\ 1000}{2000}$$

Where, LR = Lime Requirement; EA= Exchangeable Acidity; BD = Bulk Density (Kamprath, 1984).

2.3. Soil Sampling, Preparation and Analysis

Soil samples from the experimental site were taken before planting and after harvesting of faba bean. First, one representative composite soil sample was collected from ploughed and leveled field from three places diagonally across the field (by zigzag method) with auger from 0 to 20 cm depth of top soil and composited to make one representative soil sample before soil treated by lime application. The composited soil sample taken was subjected to analysis for soil physico-chemical parameters before planting. Secondly, after the crop was harvested, from 45 plots representative soil samples were taken for each treatment from each replication. The soil samples collected were composited treatment wise to make a total of 15 composited soil samples. The composited samples were air-dried at room temperature, thoroughly mixed and ground to pass through a 2 mm sieve and were transported to soil laboratory for analysis of selected soil physico-chemical properties. The selected physical and chemical properties of composited soil sample subjected to analysis were (soil texture, Exchangeable Acidity, Soil pH, organic carbon (OC), total N, available P, exchangeable bases (Na, K, Ca, and Mg) and CEC following standard laboratory procedures for each parameter.

Undisturbed surface soil sample was collected using core sampler from the experimental field to determine bulk density of the soil before planting. The soil core was removed from undisturbed soil by driving the cylinder into the soil with block of wood and hammer. The soil core was examined and the ends were trimmed carefully. Then the soil and the cylinder were weighed; the weight of the soil sample alone was calculated by subtracting the weight of the cylinder and the oven-dry weight of the sample was calculated. Lastly, the bulk density (gcm^{-3}) the soil was calculated from weight of oven dry soil core (g) and volume of soil core (cm^3) (George *et al*., 2013). Soil texture was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962) and organic matter content was determined by the oxidation of organic carbon with acid potassium di-chromate ($K_2Cr_2O_7$) medium using the Walkley and Black method as described by Dewis and Freitas (1970). The pH of the soil was measured or determined by using potentiometric method at 1:2.5 (weight/ volume) soil to water dilution ratio using a glass electrode attached to digital pH meter (Page, 1982).

Total nitrogen was determined by using Kjeldahl method as described by Jackson (1967) and also available phosphorus was determined by using the Bray II method (Bary and Kurtz, 1945). Cation exchange capacity (CEC**)** was measured after saturating the soil with 1N ammonium acetate (NH_4OAC) and displacing it with 1N NaOAC and was determined from ammonium acetate saturated samples that was subsequently replaced by Na from a percolated sodium chloride solution (Chapman, 1965). The excess salt was removed by washing with alcohol and the ammonium that was replaced by sodium was measured by using the Kjeldahl method as described by Ranst *et al.,* (1999). Exchangeable bases were extracted with 1M ammonium acetate at pH 7.0. Exchangeable Ca and Mg were measured from the extract with atomic absorption spectrophotometry while exchangeable K and Na were determined from the same extract with flame photometry. Total exchangeable acidity was determined by saturating the soil samples with potassium chloride solution and titrated with sodium hydroxide as described by Mclean (1965).

2.4. Data Collection

The parameters studied during the study of the experiment were: total number of nodules $plant^{-1}$, number of effective and non-effective nodules $plant^{-1}$, nodules volume $plant^{-1}$ (cm^3), nodules fresh and dry weight (g), dry biomass yield (kg ha^{-1}) and grain yield (kg ha^{-1}).

The total number of nodules: Total number of nodules was determined by counting nodules from five plants of central rows randomly taken from each plot at flowering. The roots were carefully exposed with the bulk of root mass and nodules by using shovel and hoe. The nodules were separated gently from the soil by washing in tap water and the total number of nodules was determined by counting and averaged as per plant.

Number of Effective and non-effective nodules: The number of effective and non-effective nodules were separated by observing colors of a cross section of a nodule after dissecting it using a scalpel. Those nodules showed a pink to dark-red color are considered effective, whereas a green and / or white color indicates non-effective nodulation. Then the number was adjusted to number of effective and non-effective nodules per plant.

Volume of the nodules: The volume of nodules (cm^3) from five plants was placed on already measured water in a cylinder and the amount of displaced water indicates the volume of total nodules and it was averaged as per plant. The total volume was divided by total number of nodules to determine the volume of each nodule.

Nodule dry weight: It was recorded from five plants after drying them in an oven at 70 ^oC for 24 hours and weighed and averaged as per plant (g $plant^{-1}$).

Dry biomass (kg ha^{-1}): Dry biomass was obtained from plants harvested at maturity from net plot area (six central rows) of each plot and sun dried it for 48 hrs. Then the data was converted to kg per hectare.

Grain yield (kg ha^{-1}): Grain yield was harvested from six central rows that were considered for dry biomass yield were threshed to determine grain yield after adjusting the moisture content of the seeds 10%. Finally, yield per plot was converted to per hectare and the average yield was reported in kg ha^{-1}.

Agronomic Phosphorus Utilization Efficiency (APUE) (kg kg^{-1}): Agronomic phosphorus use efficiency was calculated for grain yield or agronomic efficiency as the economic production obtained per unit of nutrient applied (Fageria and Barbosa, 2007).

$$\text{APUE (kg grain yield kg}^{-1}\text{ P)} = \frac{GDWf - GDWc}{Ps}$$

Where, GDWf = grain dry weight of fertilized treatment (kg ha^{-1})
GDWc = grain dry weight of control treatment (kg ha^{-1})
Ps = Phosphorus supplied (kg)

3. RESULTS AND DISCUSSION

3.1. Soil Physico-chemical Properties of the Experimental Site

The soil particle size distribution of the experimental site was: sand (25.36%), silt (41.50%) and clay (33.14%) respectively in which the textural class of soils of the experimental sites was clay loam. The soil reaction of the experimental sites is strongly acidic. This indicates that the soil experimental site requires soil amendment with lime to make it suitable for optimum growth and yield of most crops. The initial soil pH of the experimental site was 4.51 and found in strongly acidic range according to Tekalign (1991) rating. The available P level recorded in the experimental site was (0.7 mg kg^{-1} of soil) which is found in very low range as (Cottenie, 1980; Bray and Kurz, 1945) rating. This indicates that the available P of the study area is very low which point us P fertilizer application is crucial for the study area in order to maximize faba bean production. The low available phosphorus could be due to P fixation in such acidic soils and removal of basic cations such as Ca^{2+}, Mg^{2+}, Na^+ and K^+ from the top soil because of high rain fall of the area. The total nitrogen percentage of the experimental field was 0.18% and found in low range as Tekalign (1991) rating. The cation exchange capacity of the experimental soil was 14.1cmol (+) kg^{-1} which is found in low range according to Berhanu (1980) rating. The total carbon content in the soils was 1.33%. The concentrations of exchangeable Ca (7.7 cmol (+) kg^{-1}), Mg (1.68 cmol (+) kg^{-1}), and Na (0.47 cmol (+) kg^{-1}) were medium to low except that of K (1.23 cmol (+) kg^{-1}) which was high. The bulk density of the soils of the experimental site is 1.39 g/cm^3.

3.2. Effect of Phosphorus Fertilizer Rates on Some Soil Chemical Properties

The post soil analysis results are indicated in Table 1. Application of phosphorus fertilizer rates had no significant ($P>0.05$) effect on soil chemical properties such as soil pH, Exchangeable acidity, Organic Carbon, CEC and exchangeable basic caions ($Ca^{2+,}$ Mg^{2+}, Na^+ and k^+) while, it significantly ($P<0.05$) influenced the concentration of available P and total nitrogen of the soil.

The mean values of available P of the soil was showed an increasing order as P level increasing. As phosphorus fertilizer level increased from 0 to 40 kg P ha^{-1} the available P of the soil increased by 237%. Higher concentration of available P (9.94 mg kg^{-1}) was recorded at phosphorus level 40 kg p ha^{-1}, whereas the lowest concentration of available P (2.95 mg kg^{-1}) found from control plot (0 kg P ha^{-1}). This might indicate that application of P fertilizer to soils increase the concentration of available phosphorus in the soil. The increase in available P concentration in soil might be due to the application of lime with corresponding application of phosphate fertilizer that enhanced the availability of P in the soil solution and the quantity of P retained at specified conditions of intensity and buffering capacity of soils and the lowest available P at the zero rate might be due to utilization of residual P by plant and further adsorption by Al (Alley and Zelazeny, 1997). The low available P in the control plot might be due to further fixation of it by soil colloids and other losses through cultural practices (Barber *et al*., 1984).

Table 1. Effect of Phosphorus fertilizer rates on selected Soil Chemical properties of experimental site after harvesting

Phosphorus rates (kg ha^{-1})	pH	Available Phosphorus mg kg^{-1}	Exchangeable Acidity (cmol(+)kg^{-1})	Organic Carbon (%)	Cation Exchangeable Capacity (cmol (+)kg^{-1})	Total Nitrogen (%)	Exchangeable Bases (cmol(+)kg^{-1})			
							Ca^{2+}	Mg^{2+}	Na^{1+}	K^{1+}
0	5.43	2.95^{b}	0.13	0.90	16.20	0.28^{a}	6.67	3.14	0.34	1.24
10	5.37	4.35^{b}	0.15	1.26	19.00	0.25^{b}	6.42	3.84	0.37	1.52
20	5.40	8.20^{a}	0.13	1.33	12.20	0.28^{a}	5.47	2.89	0.37	1.14
30	5.26	9.23^{a}	0.20	1.33	18.53	0.25^{b}	4.23	3.18	0.37	1.04
40	5.31	9.94^{a}	0.19	1.31	17.30	0.29^{a}	2.99	1.69	0.32	1.36
CV (%)	2.22	20.65	31.08	26.49	31.49	3.77	46.58	54.80	13.74	27.23

Means within a column followed by the same letter are not significantly different at 5% probability level

3.3. Total Number of Nodules plant^{-1}

The mean total number of nodule plant^{-1} is indicated in Table 2. The interaction effect of varieties and phosphorus fertilizer rates had non-significant (p>0.05) difference on total number of nodule plant^{-1} of faba bean but the main effect of varieties had significant (P <0.05) effect on total number of nodules plant^{-1}. Significantly higher total number of nodules plant^{-1} (59) was recorded from Tumsa variety while the lowest total number of nodules plant^{-1} (49) was from Gebelcho variety.

Application of Phosphorus fertilizer rates had highly significant (p<0.001) effect on total number of nodules plant^{-1} (Table 2). Higher total numbers of nodules plant^{-1} (63) was obtained with application of 30 kg P ha^{-1} while the lowest (39) total number of nodules plant^{-1} was from control. Increased application of phosphorus from 0 to 30 kg P ha^{-1} was increased by 62% the total number of nodules plant^{-1} but it showed decreasing as P rate increased to 40 kg P ha^{-1}. Phosphorus rate at the rate of 30 kg ha^{-1} might be an optimum rate for obtaining better total number of nodules plant^{-1}. Thus, increasing P level up to 30 kg ha^{-1} had a directly proportional effect on the number of nodules plant^{-1} of faba bean. Similarly, Kubure *et al*. (2016) reported that application of phosphorus played a significant role in enhancing the root nodulation of faba bean in comparison with no phosphorus. Alemu (2009) also reported on fenugreek varieties and concluded that the number of nodules per plant increased with increase in the rate of P fertilizer. Likewise, Bashir *et al*. (2011) reported that phosphorus influences nodule development through its basic functions in plants as an energy source. It plays a vital function in increasing plant tip and root growth, decreasing the time needed for developing nodules to become active and of benefit to the host legume. Furthermore, P increases the number and size of nodules and the amount of nitrogen assimilated per unit weight of nodules, increasing the percent and total amount of nitrogen in the harvested portion of the host legume and improving the density of Rhizobium bacteria in the soil surrounding the root. Kasturikrishna and Ahlawat (1999) also reported that, 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. Fatima *et al*. (2007) reported that during nodulation, P is an essential ingredient for Rhizobium bacteria to convert atmospheric N_2 into an ammonium (NH_4^+) form usable by plants.

3.4. Number of Effective Nodules Plant^{-1}

Total number of effective nodules of faba bean was significantly (P<0.05) affected by the main effect of varieties and P fertilizer rates ((Table 2) but, the interaction effect of faba bean varieties and phosphorus fertilizer rates were showed non-significant (P>0.05) effects on number of effective nodules. Significantly higher number of effective nodules plant^{-1} (52) was recorded from variety Tumsa while, the lowest number of effective nodules plant $^{-1}$ (43) was recorded from variety Gebelcho (Table 2).

Application of P fertilizer rates showed highly significant (P<0.001) effect on the total number of effective nodules plant^{-1} (Table 2). The number of effective nodules plant^{-1} was increasing as P rate increasing from 0 to 30 kg P ha^{-1} and the number of effective nodules plant^{-1} increased by 53% but, it showed decreasing as P rate increased to 40 kg P ha^{-1} which is similar with total number of nodules $plant^{-1}$. However, the highest total number of effective nodules $plant^{-1}$ (55) was obtained at P rate of 20 kg P ha^{-1} while the lowest total number of effective nodules $plant^{-1}$ (36) was recorded from control (0 kg P ha^{-1}) (Table 2). This result confirms that the current blanket recommended rate of P is still working for faba bean production in the area.

3.5. Number of Non-Effective Nodules Plant^{-1}

The mean number of non-effective nodules was revealed significant ($P<0.05$) difference due to the main effects of faba bean varieties and application of P fertilizer rates (Table 2) but, the interaction effect of faba bean and P fertilizer rates showed no significant ($P>0.05$) variation on number of non-effective nodules $plant^{-1}$. Significantly higher total number of non-effective nodules $plant^{-1}$ (7.20) was recorded from Tumsa variety while the lowest non -effective nodules $plant^{-1}$(5.44) was obtained from Gebelcho variety (Table 2). Application of P fertilizer rates showed significant ($P<0.05$) variation on the number of non–effective nodules $plant^{-1}$ (Table 2). Significantly higher number of non-effective nodules $plant^{-1}$ (7.82) was recorded application of 30 kg P ha^{-1} which is statistically not different from that of both 20 and 40 kg P ha^{-1}. However, the lowest non-effective nodules $plant^{-1}$ (4.82) was recorded from unfertilized plot (control) (Table 2).

3.6. Volume of Nodules plant^{-1}

The mean volume of nodules $plant^{-1}$ of faba bean is indicated in Table 2. Main effect of faba bean varieties was not significant ($P>0.05$) affected mean value of nodules volume $plant^{-1}$ of faba bean. Applications of Phosphorous rates were significantly ($P<0.05$) affected volume of nodules $plant^{-1}$ of faba bean. Higher mean values of (1.71 cm^3) volume of nodules $plant^{-1}$ was recorded with application 20 kg P ha^{-1} followed by 30 and 40 kg P ha^{-1}(1.57 cm^3). Phosphorus at the rate of 20 kg ha^{-1} might be an optimum rate for best results in volume nodules $plant^{-1}$, which confirmed the current recommended rate of phosphorus for faba bean production. Thus, increasing P level up to 20 kg ha^{-1} had a directly proportional effect on the volume of nodules $plant^{-1}$ of faba bean. Similarly, Alemu (2009) reported that highly significant variations were observed on nodules volume $plant^{-1}$of fenugreek varieties in response to increasing of phosphorus application.

3.7. Nodules Fresh and Dry Weight Plant^{-1}

Applications of different levels of phosphorus and varieties had a non- significant ($P>0.05$) effect on both nodules fresh weight and dry weight of faba bean (Table2). Non-significantly higher mean values of nodules fresh weight and dry weight (1.47 g) and (0.20 g) were recorded from Tumsa variety whereas; the lowest nodules fresh weight and dry weight (1.19g) and (0.16 g) were recorded from Gebelcho variety respectively. This indicates that the efficiency of fixing atmospheric nitrogen depends on faba bean varieties. Higher mean nodules fresh weight and dry weight $plant^{-1}$ of faba bean (1.53 g) and (0.20 g) was recorded with application of 20 kg P ha^{-1}, followed by 30 kg ha^{-1}(1.47 g and 0.20 g)(Table 2). The lowest nodules fresh weight and dry weight $plant^{-1}$ (0.99 g and 0.13 g) were obtained from control plots (0 kg P ha^{-1}) respectively. The 20 kg P ha^{-1} rate seems to be the most economical for nodule biomass weight of faba bean. It also indicated that increasing P above 20 kg ha^{-1} had nothing to do with the improvement of crop performance in nodule fresh and dry weight of the data (Table 2). In contrary, Kubure *et al*. (2016) reported that application of phosphorus has no discernible influence on the dry biomass of root nodules of faba bean as compared with no phosphorus application.

Table 2.The main effect of varieties and phosphorus rates on total number of nodules, effective nodules, non-effective nodules, nodules volume, nodules fresh and dry weight per plant and plant height of faba bean

Treatments	Total number of nodules $plant^{-1}$	Effective nodules $plant^{-1}$	Non- effective nodules $plant^{-1}$	Nodule volume $plant^{-1}$ (cm^3)	Nodule fresh weight $plant^{-1}$ (g)	Nodule dry weight $plant^{-1}$ (g)
Varieties						
Tumsa	58.92^{a}	52.44^{a}	7.20^{a}	1.56	1.47	0.20
Gebelcho	48.65^{b}	43.24^{b}	5.44^{b}	1.32	1.19	0.16
Dosha	56.73^{a}	49.75^{ab}	6.45^{ab}	1.49	1.33	0.17
LSD (5%)	7.5	7.33	1.44	NS	NS	NS
Phosphorus rate (kg ha^{-1})						
0	39.09^{c}	35.47^{b}	4.82^{b}	1.01^{b}	0.99	0.13
10	51.36^{b}	46.13^{a}	5.42^{b}	1.43^{a}	1.27	0.17
20	61.93^{a}	54.71^{a}	7.31^{a}	1.71^{a}	1.53	0.20
30	63.31^{a}	54.11^{a}	7.82^{a}	1.57^{a}	1.47	0.20
40	58.16^{ab}	51.96^{a}	6.44^{ab}	1.57^{a}	1.40	0.18
LSD (5%)	9.67	9.47	1.87	0.39	NS	NS
CV (%)	18.3	20.2	30.4	27.4	30.7	31.4

Means within a column followed by the same letter are not significantly different at 1 and 5% probability level. NS = Not significantly different at 5% and 1% probability level respectively.

3.8. Dry Biomass Yield

The mean dry biomass yield of faba bean is indicated in Table 3. Main effect of varieties and phosphorus rates were highly significantly ($P<0.001$) affected the dry biomass yield of faba bean, whereas, the interaction of both variety and P rates was non-significantly ($P>0.05$) affected dry biomass yield of faba bean. Significantly higher mean value of dry biomass yield of (13905 kg ha^{-1}) was obtained from Tumsa variety whereas, the lowest mean value of dry biomass yield (12153 kg ha^{-1}) was obtained from Gebelcho variety which is statistically at par with Dosha (12559 kg ha^{-1}). Likewise, Ashenafi and Mekuria (2015) reported that dry matter biomass had significant different on faba bean varieties. Higher mean dry biomass weight (11470Kg ha^{-1}) was recorded from Tumsa variety. This result also in agreement with Abdalla *et al*. (2015) who reported that reported that dry biomass was significantly varies with faba bean varieties. Mean dry biomass yield of faba bean was highly significantly ($P<0.001$) affected by different levels of phosphorus fertilizer (Table 3). Significantly higher mean dry biomass yield of (14158 kg ha^{-1}) was produced with application of 40 kg P ha^{-1} that was at par with 20 kg P ha^{-1} and 30 kg P ha^{-1} respectively (Table 3). The lower dry biomass yield (10970 kg ha^{-1}) was obtained from 0 kg P ha^{-1}. As phosphorus levels increase from 0 kg P ha^{-1} to 40 kg P ha^{-1} the dry biomass yield was increased by 29% (Table 3). Similarly, Tadele *et al.* (2016) found that the application of FYM and P fertilizer had significant ($p<0.05$) influenced biomass yield of faba bean.

Since phosphorus is responsible for good root growth and development it directly affects the overall plant performance, as a result a good and optimum supply of P is important for crops to explore more soil nutrients and moisture. This is why the above ground dry biomass yield was the lowest in the control plots because lack of P impacts the roots growth of the plants which in turn negatively affected the other physiological functions of the faba bean plants in the control plots. As observed from the mean values of the data indicated in Table 3 dry biomass accumulation increases with application of phosphorus fertilizer rates. This increment in above ground dry biomass yield with application of P fertilizer might be due to supplying adequate of P could be contributed to an increase in number of pods, plant height, leaf area and other crop physio-morphology.

3.9. Grain Yield

The mean grain yield of faba bean is indicated in Table 3. Main effect of varieties had non-significant (P>0.05) effect on mean grain yield of faba bean (Table 3). Non-significantly higher mean grain yield of (5937 kg ha^{-1}) was recorded from Dosha variety as compared to Gebelcho variety whereas the lower grain yield of (5748 kg ha^{-1}) followed by Tumsa (5924 kg ha^{-1}) variety (Table 3). In contrary Ashenafi and Mekuria (2015) reported that there was a variation between the varieties for most yield and yield components including grain yield. Interaction effect of faba bean varieties and P application rates also did not influence grain yield significantly (P>0.05).

Application of different levels of phosphorus had a highly significant (P<0.001) effect on mean grain yield of faba bean (Table 3). Application of 40 kg ha $^{-1}$ resulted in higher grain yield (6323 kg ha^{-1}), which was statistically at par with P applied at the rates of 20 kg P ha^{-1} and 30 kg P ha^{-1}. All applied P fertilizer rates significantly increased grain yield of faba bean over the control. The lowest gain yield (5076 kg ha^{-1}) was recorded from control. As phosphorus rates increased from 0 kg ha^{-1} to 40 kg ha^{-1} the grain yield of faba bean increased by 25%. This increase in yield is therefore, attributed to the increased available P due to P fertilizers application. As phosphorus rates increased from 0 kg ha^{-1} to 40 kg ha^{-1} progressive increases in mean grain yield of faba bean. This increase in grain yield might be attributed due to P fertilizer application which indicates that the soil of the experimental field is low in available P. This finding is agreed with Tadele *et al.* (2016) who found that the application of FYM and P fertilizer on yield parameters of faba bean had positively (p<0.05) influenced such as biomass, grain yield, straw weight and thousand seeds weight. Similarly, Kubure et al. (2016) reported fertilization of faba bean with resulted in substantial increase in seed and biological yields over no fertilizer. These results agree with Masood *et al.* (2011) who reported that grain yield of faba bean was significantly affected by different levels of Phosphorous.

Table 3.The main effects of varieties and phosphorus rates on harvest index, above ground biomass yield and grain yield of faba bean

Varieties	Dry biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Tumsa	13905^{a}	5924
Gebelcho	12153^{b}	5748
Dosha	12559^{b}	5937
LSD (0.05)	789.53	NS
Phosphorus rate (kg ha^{-1})		
0	10970^{c}	5076^{c}
10	12092^{b}	5693^{b}
20	13178^{a}	6008^{ab}
30	13962^{a}	6248^{a}
40	14158^{a}	6323^{a}
LSD (0.05)	1019	463
CV (%)	8.2	8.17

Means within a column followed by the same letter are not significantly different at 1 and 5 % probability level. NS = Not significantly different at 5% and 1% probability level respectively.

3.10. Agronomic Phosphorus Utilization Efficiency

Phosphorus utilization efficiency was calculated for faba bean grain yield per unit of P fertilizer application. Phosphorus utilization efficiency was not significantly (P>0.05) affected by faba bean varieties (Table 4). Non-significantly higher phosphorus utilization efficiency was recorded for variety Tumsa (253 kg grain kg^{-1} P) followed by variety Dosha (248 kg grain kg^{-1} P), whereas, the lowest (240 kg grain kg^{-1} P) was obtained for variety Gebelcho (Table 4). Similarly, Amsalu *et al.* (2016) found that considerable difference in P utilization efficiency among six faba bean varieties. Application of different rates of phosphorus had highly significant (P<0.05) effect on faba bean phosphorus utilization efficiency. Application of P at the rate of 10 kg P ha^{-1} resulted in higher phosphorus utilization efficiency of (569 kg grain kg^{-1} P) followed by 20 kg P ha^{-1}(300 kg grain kg^{-1} P). As P levels increase from 10 kg P ha^{-1} to 40 kg P ha^{-1} the phosphorus utilization efficiency of faba bean (kg grain kg^{-1} P) was decreased by 6.62% (Table 4). In contrary, (Amsalu *et al.* , 2016; Rasul ,2017) who reported that phosphorus application had no significant effect on PUE of faba bean crop and the decreased phosphorus use efficiency was seen at highest P rates application.

Table 4.The main effects of varieties and phosphorus rates on phosphorus utilization efficiency

Varieties	Phosphorus utilization efficiency (kg grain kg^{-1} P)
Tumsa	253.453
Gebelcho	240.207
Dosha	247.993
LSD (0.05)	NS
Phosphorus rate (kg ha^{-1})	
0	0.000
10	569.3[a]
20	300.4[b]
30	208.3[c]
40	158.1[d]
LSD (0.05)	20.13
CV (%)	8.43

Means within a column followed by the same letter are not significantly different at 5% level of significance. NS= Not significantly different at 5% and 1% probability level respectively.

3.11. Correlation of nodule parameters and yield component of faba bean due to Main Effect of varieties and Phosphorus rates

The Result of the linear correlation coefficients of parameters studied is indicated in Table 5. Total number of nodules $plant^{-1}$ was significant (P<0.001) and strongly positively correlated to effective nodules $plant^{-1}$ (0.97), non-effective nodules $plant^{-1}$ (0.45), nodules volume $plant^{-1}$ (0.81), nodules fresh weight (0.80) and dry weight (0.74) and dry biomass yield. Direct relationships of biomass yield, nodulation, shoot and root dry matter yield with grain yield or nodulation are strongly in support of Achakzai and Kayani (2002) and Workineh *et al*. (2012). The number of effective nodules $plant^{-1}$ was positively significantly (P<0.05) correlated with number of non-effective nodules $plant^{-1}$, nodules volume $plant^{-1}$, nodules fresh and dry weight.

The number of non-effective nodules $plant^{-1}$ had significantly (P<0.05) positively correlated with nodules volume $plant^{-1}$, dry biomass and grain yield. Non-effective nodules $plant^{-1}$ was also non-significantly positively associated with faba bean nodules fresh and dry weight $plant^{-1}$. Nodules volumes $plant^{-1}$ of faba bean was significantly positively correlated to nodules fresh and dry weight (0.85 and 0.80) while, it was non-significantly positively associated dry biomass yield and grain yield. Nodules fresh and dry weight were non-significantly positively associated with dry biomass yield and grain yield of faba bean, but nodules fresh weight was significant and positively correlated with nodules dry weight. However dry biomass yield was significant (P<0.001) and strongly positively correlated with grain yield (0.85) of faba bean (Table 5). Ashenafi and Mekuria (2015) found that grain yield of faba ban had positive and highly significant association with seed per pod and dry biomass yield.

Table 5. Correlation matrix of yield and yield component of faba bean due to main effect of varieties and P rates

	TNNP	ENP	NENP	NVP	NFWP	NDWP	DBY	GY
TNNP		0.97**	0.45**	0.81**	0.80**	0.74**	0.31*	0.25
ENP			0.28*	0.81*	0.82*	0.79*	0.19	0.14
NENP				0.34*	0.28	0.18	0.60*	0.46*
NVP					0.85**	0.80**	0.27	0.25
NFWP						0.86*	0.17	0.12
NDWP							0.13	0.11
DBY								0.85**
GY								

*and ** = correlation is significant at (0.05) and (0.01) levels of probability respectively, TNNP = Total Number of Nodules $Plant^{-1}$, ENP = Effective Nodules $Plant^{-1}$, NENP = Non Effective Nodules $Plant^{-1}$, NVP = Nodule Volume $Plant^{-1}$, NFWP = Nodule fresh Weight $Plant^{-1}$, NDWP = Nodule Dry Weight $Plant^{-1}$, DBY = Dry Biomass Yield ($kgha^{-1}$), GY = Grain Yield ($kgha^{-1}$).

4. CONCLUSIONS

The post soil analysis indicates, phosphorus rates had significantly affected ($P<0.05$) both available p and soil total N, indicating that available P of the soil showed an increasing trend as P level increasing. The main effect of varieties had significantly improved mean total number of nodule, effective nodules, non-effective nodules and higher number was recorded from Tumsa variety.

Application of 30 kg p ha^{-1} gave significantly higher total number of nodules per plant, number of non-effective nodules per plant, nodule volume per plant for faba bean. Significantly higher biomass yield (14158 kg ha^{-1}) and grain yield of (6323 kg ha^{-1}) were obtained from application of 40 kg P ha^{-1}. Application of P rates highly significantly ($P<0.001$) improved on agronomic phosphorus utilization efficiency of faba bean. Significantly higher APUE was recorded from plots applied with 10 kg P ha^{-1}. Therefore, it can be concluded that application of 30 kg P ha^{-1} proved to be productive and economical feasible for faba bean production and be recommended for faba bean production in Lemu Bilbil area and similar agro-ecologies.

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