Nodulation, Grain Yield and Yield Components of Faba bean (*Vicia fabae* L.) as Influenced by Rhizobium inoculation and Phosphorus fertilization in Moretna Jiru District, Eastern Amhara, Ethiopia

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Abstract

The on-farm experiment was conducted at Moretna Jiru district, Amhara Region, Ethiopia during the main rainy seasons of 2016/17 and 2017/18. The objective of the study was to evaluate the effectiveness of different commercial and new rhizobia strains as well as to evaluate the effect of phosphorus fertilizer on nodulation and grain yield of faba bean in the study area. The experiment comprised of three Rhizobial strain (EAL-110, FB-1035 and FB-1018), one Phosphorus level (10 kg P ha) and control (with-out inoculation and P application) which were laid out in randomized complete block design (RCBD) with three replications. The analysis of variance showed that except nodule size in 2017/18, all the tested nodulation parameters were not affected by the treatments. Plant height which was obtained from both years was significantly affected by the treatments. In 2016/17, significantly the highest plant height (86.4 cm) was observed from combined application of EAL-110 strain with 10 kg P ha^{-1}. The lowest plant height (78.4 cm) was observed with inoculation of the seed of faba bean with strain FB-1018. In 2017/18 the highest plant height (80.0 cm) was observed with sole application of strain FB-1035. In 2016/17, significantly the highest number of pod per plant (21.4) was observed with combined application of strain EAL-110. In 2017/18, significantly the highest number of pods per plant (26.8) was observed with combined application of EAL-110 with 10 kg P. In 2016/17, significantly the highest seed yield (2537 kg ha^{-1}) was observed with combined application of EAL-110 with 10kg P ha^{-1}. The lowest seed yield (1931.6 kg ha^{-1}) was observed from the control plot. In 2017/18, significantly the highest seed yield was observed with inoculation of the seed of faba bean with strain EAL-110 alone. The partial budget analysis indicated that the highest mean net benefit (43800.7 birr ha^{-1}) was obtained when EAL-110 Rhizobium strain was applied with 10 kg P ha^{-1}. Hence, Rhizobium inoculation of EAL-110 with 10 kg P ha^{-1} could be recommended for faba bean production at the experimental locations in Moretna Jiru district.

Keywords*:*Faba bean, Inoculation, Nodulation, Rhizobium, Yield

Introduction

Faba bean (*Vicia fabae* L.) is a major cool-season food legume that occupies about 34% of the total cultivated land from pulses in Ethiopia (CSA, 2013). Amhara and Oromia regional states are the two favorable areas in Ethiopia where production of faba bean is highest. Those two regions account for 85% of the national faba bean production (IFPRI, 2010). Faba bean is grown in the main season, on both red and black soils.

The crop has been an important protein source for the human diet. The straw of the crop is used as animal food. Faba bean is a legume crop capable of fixing nitrogen by forming an association with root nodulating bacteria group called *Rhizobium leguminosarum* biovar vicia. As a result, it improves the fertility status of the soil and makes N for subsequent crops (Amanuel *et al*., 2000; Habtegebriel *et al*., 2007). Some report indicated faba bean derive the highest percentage of N from the atmosphere (Hardarson *et al.*, 1991) and the amount of nitrogen fixed by faba bean have been 240-325 kg ha^{-1} (Somasegaran and Hoben, 1994).

Even though faba bean is of such importance in Ethiopia, the national yield has remained low; and According to Central Statistics Agency of Ethiopia (2012/13), the national average yield of faba bean is 1.5 tones ha^{-1}. Several biotic and abiotic factors contributed to the low productivity of the crop. The major biotic factor includes poor soil fertility and low existence of effective indigenous rhizobia population in the area (Carter *et al*., 1998). The application of chemical fertilizer, particularly phosphorus is needed to improve the production of the crop (Otieno *et al*., 2009). External seed inoculation of rhizobia is one of the practices to increase the nitrogen fixation potential of the faba bean crop and hence the yield of the crops especially in areas where low population of effective indigenous rhizobia or due to higher competitions with non-effective ones (Tolera *et al*., 2009). The objective of this study was therefore to evaluate the effectiveness of different commercial and new rhizobia strains and to evaluate the effect of phosphorus on nodulation and grain yield of faba bean in Moretina Jiru and similar agro-ecologies and soil types areas.

Materials and Methods

Description of the study area On-farm experiment was conducted at Moretna Jiru district, Amhara Region, Ethiopia during the main rainy seasons of 2016 17 and 2017 18. The average annual rainfall from the nearby metrological station (Enewari) is 899.01 mm having a mean minimum and maximum temperature of 21.39 and 9.09°C respectively. Vertisols are the dominant soil type in the areas. The crops widely grown in the study area include wheat, Tef, faba bean and lentil, whereas chickpea, grass pea and others have low area coverage and mostly grow on residual soil moisture at the end of the rainy season. Specifically, the experiment was conducted at 9^{0}52'18.07"N, 39^{0}10'19.34"E (Site 1), 9^{0}52'21.58"N, 39^{0}11'38.36"E (Site 2), 9^{0}50'53.26"N, 39^{0}12'42.58"E (Site 3), 9^{0}49'33.68"N, 39^{0}12'26.19"E (Site 4), 9^{0}54'26.65"N, 39^{0}10'17.54"E (Site 5).

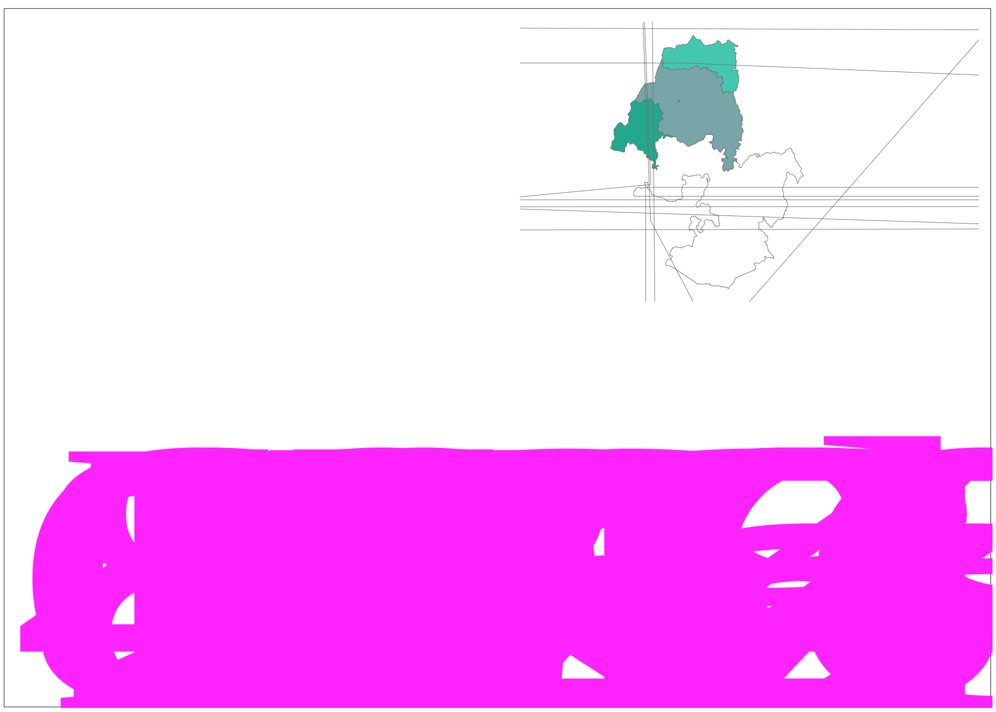

Figure 1. Location Map of the study area

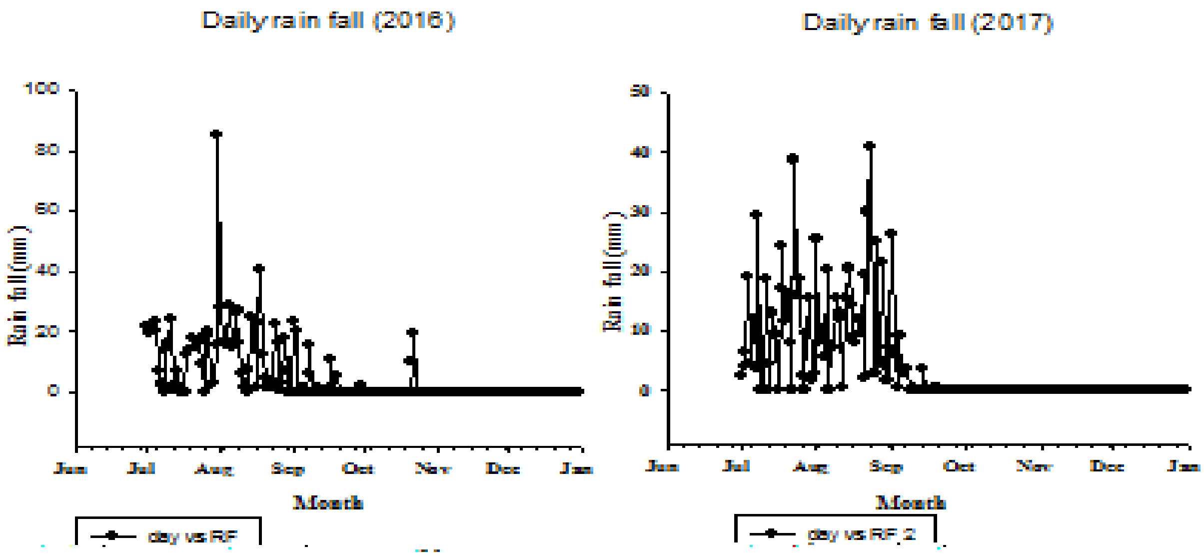

Figure 2. Daily rainfall distribution during the experiment (planting to late pod setting stage)

Experimental detail

Soil sample collection and processing

Before starting the experiment, initial composite soil samples were collected from the experimental plots. The samples were analyzed for texture, pH, Av.P, OC and TN. Soil particle size distribution was determined by the hydrometer method (Bouyoucos, 1951). Soil pH was measured with a digital pH meter potentiometrically in supernatant suspension of 1:2.5 soils to distilled water ratio (Van Reeuwijk, 1992). Organic carbon (OC) was determined by the dichromate oxidation method (Walkley and Black, 1934). Total N in the soil was measured by the micro Kjeldahl method (Jackson, 1958). Available P was analyzed by Olsen method (Olsen *et al*., 1954) colorimetrically by the ascorbic acid- molybdate blue method (Watanabe and Olsen, 1965).

Experimental design and treatments

The experiment comprised of seven treatments with three rhizobia strains (EAL-110, strain FB-1035 and strain FB-1018) and a combination of those strains with chemical fertilizer (10 kg P ha^{-1}). The experiment was laid out in a randomized block design with three replications. The plot size was 3.6 m x 3m.

Treatments:

1. Control (No strain and P fertilizer)
2. Strain FB-1035
3. Strain FB-1018
4. Strain EAL-110
5. Strain FB-1035 + 10 kg P ha^{-1}
6. Strain FB-1018 + 10 kg P ha^{-1}
7. Strain EAL-110 + 10 kg P ha^{-1}

Source of rhizobial isolates

Commercially available *Rhizobium* strain EAL-110 was obtained from MBI (Menagesha Biotechnology Industry). While the two available *Rhizobium* strain (FB-1035 and FB-1018) was obtained from Holeta Agricultural Research Center.

Source of improved seeds

The Faba bean variety “Dagem” was used as testing crop for the experiment. The variety was selected based on the recommendation of Debre Birhan Agricultural Research Center for the area.

Method of seed inoculation

Seed inoculation was performed before sowing using the procedure developed by Fatima *et al*. (2007). To ensure the sticking of the applied inoculant to the seeds, the required quantity of seed was suspended in 1:1 ratio in 10% sugar solution. The inoculant was gently mixed with dry seeds at the rate of 10 g per kg of seed. Inoculation was done just before sowing under shade to maintain the viability of cells and allow to air dry for a few minutes and then the inoculated seeds were sown at 40 cm between rows and 10 cm between plants. To avoid contamination, plots with un-inoculated seeds were planted first followed by the inoculated ones.

Data collection

Data collected at the flowering stage

Sampling for nodulation was performed by excavating the roots of plants randomly from two rows next to border rows of each plot at the mid flowering stage of the crop. The plants from each plot were used to record the number of effective nodules, nodule size and nodule volume.

Data collected at early pod setting stage and after harvesting

At early pod setting and after harvesting plant height, number of pod per plant, seed yield, straw yield and 1000 seed weight was determined

Other agronomic management

Disease and pest control: (Redomil) and (Caratin) were sprayed to control faba bean gall disease (*kormed*) and bollworm respectively.

Data analysis

The collected data were subjected to analyses of variance (ANOVA) on the selected parameters using SAS 9.1 statistical software. Where ever the treatment effects were significant, mean separations were made using the least significance (LSD) test at a 5% level of probability (Gomez, 1984).

Economic analysis

Based on the procedure described by CIMMYT (1988), economic analysis was done using partial budget analysis. For partial budget analysis, the variable cost of fertilizer, labor and rhizobial inoculant were taken at the time of planting and during other operations. The price of faba bean grain and straw were considered. The average yield was adjusted downward by 10 % to reflect the farmer's field yield as described by CIMMYT (1988). The return was calculated as total gross return minus total variable cost. Field seed price of faba bean (16.5 Birr kg^{-1} seed), inoculant (240 Birr ha^{-1}), straw (4.00 Birr kg^{-1}), phosphorus fertilizer (9.634 Birr kg^{-1}) and labor cost (100 Birr per person per day) were used for variable cost determination. All input and output cost for economic analysis was based on mean value over location.

Result and Discussion

Selected Physico-chemical Properties of the Soils of the Study Sites

Soil texture is one of the inherent soil properties less affected by management and which determines nutrient status, organic matter content, air circulation and water holding capacity of a given soil. Based on the soil analysis made, the soil texture of the entire site was clay. In agreement with the present study, different scholars reported that the particle size distribution of vertisols of Ethiopia are dominated by clay (Kamara *et al*., 1989; Lemma and Smit, 2008; Debele, 1985 and Tesgaye, 1992).

The results of the selected soil physical and chemical properties are presented in Table 1. The pH of the experimental soils ranged from 6.4 to 6.9. According to Tekalign (1991) all sites are rated as neutral. If all other conditions are constant this soil pH is the most suitable for major field crops including faba bean. This is actually because this pH of the soil has the greatest role in the high population density and presence of persistence rhizobia in the soil (Martyniuk and Oron, 2008). This is primarily because leguminous plants grow less in acid soil than in neutral or slightly alkaline soil which could be due to lowered colonization of *Rhizobium* in the soil and rhizosphere leading to inadequate nodulation. Furthermore, in low pH soils, sensitivity of early nodulation of pasture and grain legumes low content of available phosphorus (P), calcium (Ca), magnesium (Mg) and molybdenum (Mo) (Rengel, 2002) are common phenomenon. Moreover, low soil pH may have toxic levels of aluminum, all of which can affect the vigor and health of rhizobia (Subba Rao, 1999).

According to Tekalign (1991), the entire site had low OM content (Table 1) and ranged from 0.55 to 1.38. This is because of continuous cultivation without returning residue to the soil. Similarly, different authors reported that vertsols of Ethiopian soil are low in organic matter content (Fassil and Charles, 2009; Kamara and Haque, 1987; Giday *et al*., 2015; Kiflu and Beyene, 2013). According to Asfaw and Aynabeba (1998) low soil organic matter might contribute much to the low population of resident faba bean nodulating rhizobia.

Nitrogen (N) is the fourth plant nutrient taken up by plants in the greatest quantity next to C, O and H, but it is one of the most deficient elements in the tropics for crop production (Mesfin, 1998). According to Giller (2001) the proportion of a legume's N that is derived from N fixation is strongly influenced by the amount of combined N that is available for uptake by the legume and the ability of the plant to capture and utilize that N. Nitrogen (N) derived from N fixation will be smaller when large amount of N is available in the soil.

It has been observed in Table 1, that total N in the study sites varied from 0.06% to 0.14% with a mean value of 0.25%. Based on Tekalign (1991), the total nitrogen content of all sites was low (Table 1). This indicates an external source of N (either from the application of synthetic fertilizer or organic fertilizers including bio-fertilizer) is mandatory for plant growth. In previous work, soil total N was one of the most deficient elements in Ethiopian soil including vertisols (Finck and Venkateswarlu, 1982; Mengel and Kirkby, 1987; Mesfin, 1998; Hillette *et al*., 2015).

Phosphorus deficiency is one of the significant factor that reduces the nodulation since both effective *Rhizobium* bacteria and the host crop requires this nutrient in larger quantity (Getachew and Rezene, 2006). Olsen extractable P content of the soil in the experimental sites ranged from 3.96 to 12.66 mg kg^{-1} with a mean value of 9.47 mg kg^{-1} (Table 1). According to Landon (1991), the available P was rated as low for sites 2, 3, 4 and 5 and very low in site 1. As indicated in table 1, there is variability in the available P content of the soil and the probable reason for this includes the inherent fertility difference among farms and the difference in land management between farms including the difference in fertilizer usage especially P containing fertilizer. Based on this, application of P containing fertilizer is crucial.

Table 10. Selected Physico-chemical properties of the soil

Parameters	**Before planting**					
	Sites					**Mean**
	1⁺	**2⁺**	**3⁺**	**4***	**5***	
pH (1:2.5 H_2O)	6.6	6.61	6.4	6.65	6.9	6.63
Organic Carbon (%)	0.7	0.8	0.54	0.55	0.32	0.58
Organic matter (%)	1.20	1.38	0.93	0.95	0.55	1.002
Total N (%)	0.085	0.06	0.14	0.12	0.09	0099
Av. P (mg kg^{-1} soil),	3.96	10.40	8.30	12.66	12.04	9.47
Sand (%)	10	10	12	10	6	
Silt (%)	30	26	18	12	20	
Clay (%)	60	64	70	78	74	
Textural class	Clay	Clay	Clay	Clay	Clay	

*⁺=indicates farmers field on which the experiment was conducted in 2016/17, * indicates farmers field on which the experiment was conducted in 2017/18*

Nodulation parameters

The competitive ability of the native rhizobia bacteria population could be attributed to the fact that its genetic/physiological adaptation over the introduced inoculant or from a positional advantage. The native rhizobia already occupies the soil along the root zone, whereas the artificially inoculated strains usually remain concentrated around the seeds (López-García *et al*., 2002). Hence, nodule position is one of the most important parameters in assessing the performance of nodules following their ability to fix atmospheric nitrogen. In table 2, the nodule position which was obtained from both years was not significantly influenced by the treatments. This is actually because excavating and uprooting plants from vertisols is resulted in the falling of nodules from their original position for nodulation position scoring.

Many authors have reported that legume nodules having dark pink or red colors due to the presence of leghemoglobin are an indication of the effectiveness of the rhizobial strains used, which is well correlated with nitrogen fixation (Adjei and Chambeiss, 2002; Butler and Evers, 2004). In Table 2, the number of effective nodules was not significantly influenced by the treatment. Moreover, the number of effective nodules observed in the inoculated and un-inoculated plots was comparable to each other indicating the non-effectiveness of inoculated rhizobia or competitiveness of the native rhizobia over the native rhizobia (Table 2).

Nodule volume expressed as ml per plant is also an important parameter to assess inoculation success and for strain selection on a given host legume (Msumali and Kipe-Nolt, 2002). A similar author also indicated that this parameter is less subject to such errors and have a potential to replace nodule dry weight. In Table 2, the nodule volume which was obtained from both years was not significantly influenced by either the sole application of different strains of *Rhizobium* or a combination of different *Rhizobium* with inorganic fertilizer. On the contrary, inoculating grain legumes with efficient strains of rhizobium is widely reported to increase the number, mass and volume of nodules (Shibru and Mitiku, 2000; Nuruzzaman *et al*., 2005).

Table 2. Nodulation parameters of faba bean affected by different strain and inorganic P

Treatments	2016 17			2017 18		
	NP	ENN	NV(ml)	NP	ENN	NV(ml)
Control	2.7	8.58	0.92	2.63	53.51	0.79
St.FB-1035	2.6	12.42	0.92	2.67	56.75	0.88
St.FB-1018	2.5	10.08	0.92	2.92	63.21	1.00
St. EAL-110	2.4	10.75	0.93	2.79	57.42	0.81
St.FB-1035+ 10 kg P	2.6	10.50	0.93	3.04	52.12	0.98
St.FB-1018+ 10 kg P	2.4	11.88	0.92	2.96	53.88	0.88
St. EAL-110+ 10 kg P	2.5	12.24	0.95	2.67	50.05	0.85
CV (%)	**12.56**	**22.61**	**2.58**	**15.24**	**19.56**	**12.58**
LSD (0.5)	**ns**	**ns**	**ns**	**ns**	**Ns**	**ns**

Means with the same letter are not significantly different at P<0.05 level of probability following LSD, st.= strain, NP= Nodule Position, ENN=effective Nodule Number, NV= Nodule Volume

Growth parameters

Plant height obtained from both years was significantly affected by the treatment. In 2016/17, significantly the highest plant height (86.4 cm) was observed from the combined application of EAL-110 strain with 10 kg P ha^{-1} (Table 3). The lowest plant height (78.4 cm) was observed with inoculation of the seed of faba bean with strain FB-1018. In 2017/18 the highest plant height was observed with sole application of strain FB-1035. But this treatment was statically as par with sole application of strain FB-1018, combined application of strain FB-1035 with 10 kg P ha^{-1} and combined application of strain FB-1018 with 10 kg P ha^{-1}. The lowest plant height (72.5 cm) was observed from the control in this year. Similar results were reported by Sameh *et al* (2017).

Number of pods per plant responded for the treatment in this study. In 2016/17, significantly the highest number of pods per plant (21.4) was observed with combined application of strain EAL-110. But this treatment is statically as par with the control (Table 3). The lowest number of pods per plant was observed with inoculation of the seed of faba bean with strain FB-1018. In the first year, neither the sole application of *Rhizobium* inoculation nor combined application of *Rhizobium* inoculation with 10 kg P resulted any improvement in numbers of pods per plant (Table 3). In 2017/18, significantly the highest number of pods per plant (26.8) was observed with combined application of EAL-110 with 10 kg P (Table 3). The second year result also demonstrated that number of pods per plant was increased by 1.9 (9.2%) and 4 (19.4%) with sole application of *Rhizobium* inoculation and combined application of both *Rhizobium* and P fertilizer respectively compared with uninoculated and fertilized control plot.

Thousand seed weight was improved by both *Rhizobium* inoculation and P fertilizer application compared with the control check. In 2016/17 thousand seed weight was increased by 10.1 g (3.05%) and 10.6 g (3.2%) with sole application of *Rhizobium* inoculation (St. EAL 110) and combined application of St. EAL 110+ 10 kg P respectively compared with the control. Likewise, in 2017/18, treatments St. FB 1035 and St. EAL 110+ 10 kg increased thousand seed weight by 21.2 g (6.1%) and 22.5 g (6.5%) (Table 3). The probable reason for the maximum thousand seeds weight observed in either sole application of *Rhizobium* inoculation or combined application of *Rhizobium* and P fertilizer attributed to enhanced growth and development of plants that resulted from phosphorus supply and its positive effect on nitrogen fixation. The resulting increased N availability might have promoted the supply of assimilates to seed thereby enabling them to gain more weight. In agreement with the present study, some studies found a positive response of seed weight to inoculation and P application on legumes (Namvar and Sharifi 2011; Ali *et al*. 2004; Yoseph 2011).

The analysis of variance also revealed that thousand seed weight was significantly responded for the treatment only in 2017/18. The highest hundred seed weight (370.1 g) was observed with combined application of EAL-110 strain and 10 kg P ha^{-1}. This treatment combination was found statically as par with a sole application of the three strains and combined application of strain FB-1035 with 10 kg P ha^{-1} (Table 3). While the lowest thousand seed weight (332.3 g) was observed with combined application of FB-1018 with 10 kg P ha^{-1} (Table 3) in this year.

Table 3. Growth and yield-related parameters of faba bean as affected by different strain and inorganic P

Treatments	2016 17			2017 18		
	PH (cm)	Pod per Plant	1000 seed wt (g)	PH (cm)	Pod per Plant	1000 seed wt (g)
Control	80.9^{ab}	21.3^{a}	331.1	72.5^{c}	20.6^{b}	347.6^{b}
St.FB-1035	79.3^{b}	20.5^{ab}	329.6	80.0^{a}	22.5^{b}	368.8^{a}
St.FB-1018	78.4^{b}	16.1^{e}	332.8	76.3^{a}	22.1^{b}	361.3^{a}
St. EAL 110	80.4^{ab}	16.9^{de}	341.2	77.7^{a}	22.9^{b}	366.4^{a}
St.FB-1035+ 10 kg P	84.0^{ab}	18.1^{cd}	360.9	76.9^{a}	22.8^{b}	356.5^{a}
St.FB-1018+ 10 kg P	84.3^{ab}	19.1^{bc}	340.7	76.0^{a}	24.2^{b}	332.3^{b}
St. EAL 110+ 10 kg P	86.4^{a}	21.4^{a}	341.7	74.6^{c}	26.8^{a}	370.1^{a}
CV (%)	**5.31**	**10.91**	**14.06**	**4.66**	**17.33**	**5.36**
LSD (0.5)	*	*	Ns	*	*	*

Means with the same letter are not significantly different at P>0.05 level of probability following LSD, st.= strain, PH=plant height, and p=phosphorus

Seed yield

Seed yield exhibited a significant response to the treatment in each year and combined over locations (Table 4). In 2016/7, significantly the highest seed yield (2537 kg ha^{-1}) was observed with combined application of St. EAL1110 with 10 kg P ha^{-1} (Table 4). The lowest seed yield (1931.6 kg ha^{-1}) was observed with the control plot (Table 4). Nevertheless, this treatment combination was found statically as par with the sole application of strain FB-1018. In 2017/18, significantly the highest seed yield was observed with inoculation of the seed of faba bean with strain EAL110 alone. However, it also statically as par with the sole application of strain FB-1018 and combined application of these three stains with 10 kg P ha^{-1} (Table 4). Combined over year, the highest mean seed yield which was obtained from the combined application of EAL-110 with 10 kg P ha^{-1} which increase seed yield of faba bean by 20 % (425.1 kg ha^{-1}) over the lowest seed yield (2082.4 kg ha^{-1}) observed from the control plot (Table 4). The result also indicated that the sole application of strain FB-1035, FB-1018 and EAL-110 resulted in a yield advantage of 5, 14 and 14% respectively compared with the un-inoculated and unfertilized control plot. Moreover, the combination of those strains with 10 kg P ha^{-1} resulted in a grain yield advantage of 8, 19 and 20% respectively compared with the control (Table 4).

The present study indicated that, combined application of *Rhizobium* inoculation with P fertilizer is crucial for the study site. For instance, combine application of FB-1035, FB-1018 and EAL-110 with 10 Kg P fertilizer increased seed yield of faba bean by 295.3 kg ha^{-1} (13.5%), 133 kg ha^{-1} (5.9%) and 125.6 kg ha^{-1} (5.3%) respectively, compared with sole application of each respective strain of *Rhizobium* (Table 4). Indicating that P application is crucial for the growth of host plants and effective biological nitrogen fixation. In line with this study Wassie *et al* (2008) reported that inoculation of the seed of faba bean with EAL-110, EAL120 and chemical fertilizer increased grain yield by 61%, 68% and 80%, respectively, over the control. Likewise, the application of 10 kg P ha^{-1} significantly improved grain yield and biological yield of haricot bean planted at Areka research station, SNNPR-Ethiopia (Gidago *et al*. 2012). Similar results also concluded by Negash (2000) Amanuel *et al* (2000), Sameh *et al* (2017), Evans (2005), Carter *et al* (1994). However, Abebe and Tolera reported that the introduction of a new *Rhizobium* strain to Gedo highlands did not significantly increase grain yield.

Straw yield

Straw yield which was obtained from both year and combined over locations was significantly influenced by the treatments (Table 4). Combined over years, significantly the highest straw yield was observed with combined application of EAL-110 with 10 kg P ha^{-1} which would increase straw yield by 283.8 kg (13.5%) compared with the control. Like seed yield, straw yield of faba bean also improved by combined application of *Rhizobium* inoculation and P fertilizer application. For instance, the combined application of FB-1035, FB-1018 and EAL-110 with 10 Kg P fertilizer increased straw yield of faba bean by 44.6 kg ha^{-1} (2.2%), 161.2 kg ha^{-1} (8.5%) and 28.1 kg ha^{-1} (1.4%) respectively, compared with sole application of each respective strain of *Rhizobium* (Table 4).

Table 4. Seed and straw yields of faba bean as affected by different strain and inorganic P

Treatments	Seed Yield			Straw		
	2016/17	2017/18	combined	2016/17	2017/18	combined
Control	1931.6[c]	2233.1[ab]	2082.4[b]	1706.15[c]	1917.2[bc]	1811.7[c]
St.FB-1035	2117.9[bc]	1964.8[b]	2041.35.4[ab]	1909.32[b]	2103.6[bc]	2006.5[b]
St.FB-1018	1974.4[c]	2523.4[a]	2248.9[ab]	1773.45[c]	2001.0[b]	1887.2[bc]
St. EAL-110	2223.2[bc]	2541.7[a]	2382.5[ab]	1985.82[ab]	2149.0[ab]	2067.4[ab]
St.FB-1035+ 10 kg P	2434.1[b]	2539.3[a]	2486.7[a]	1967.89[ab]	2134.4[ab]	2051.1[ab]
St.FB-1018+ 10 kg P	2262.4[bc]	2501.3[a]	2381.9[ab]	1921.81[ab]	2175.0[ab]	2048.4[ab]
St. EAL-110+ 10 kg P	2537.0[a]	2479.2[a]	2508.1[a]	2000.39[a]	2190.6[ab]	2095.5[a]
CV (%)	**7.74**	**13.67**	**14.83**	**8.76**	**13.49**	**14.24**
Sign.	**	*	**	**	*	**

Means with the same letter are not significantly different at P>0.05 level of probability following LSD, st.= strain, PH=plant height

Partial budget analysis

The assumption for partial budget analysis is that the variable cost of the treatment is different. But in our case, the total variable cost of the experiment is categorized into only three groups. With this, the determination of MRR is impossible. In this case, comparison of treatments based on net benefit is mandatory. It is quite evident from table 5, the highest mean total gross benefit (444789.1birr ha^{-1}) and mean net benefit (43800.7birr ha^{-1}) was obtained when EAL-110 *Rhizobium* strain applied with 10 kg P ha^{-1}. The next better net return was 43323.1 ha^{-1} birr which was obtained from the combined application of strain FB-1035 with 10 kg P ha^{-1}. The lowest mean total gross benefit and mean net benefit of 37445.8 birr ha^{-1} was obtained from the control check and found a net benefit penalty of 14.5% (6354.9 birr ha^{-1}).

Table 5. Partial budget Analysis

Treatment	AGY	ASY	GBG	GBS	TGB	TVC	NB
Control	1874.2	1630.5	30923.6	6522	37445.8	0	37445.8
St.FB-1035	1972.3	1805.9	32542.3	7223.4	39765.7	360	39405.7
St.FB-1018	2024	1698.5	33396.2	6793.9	40190.1	360	39830.1
St. EAL-110	2144.3	1860.7	35380	7442.6	42822.8	360	42462.8
St.FB-1035+ 10 kg P	2238	1846	36927.5	7384	44311.5	988.4	43323.1
St.FB-1018+ 10 kg P	2143.7	1843.6	35371	7374	42745.5	988.4	41757.1
St. EAL-110+ 10 kg P	2257.3	1886	37245.3	7544	44789.1	988.4	43800.7

AGY= Adjusted seed yield ((kg ha^{-1}), ASY= Adjusted straw yield (kg ha^{-1}), GBS=gross benefit from straw (ETB ha^{-1}), GBG=gross benefit from grain (ETB ha^{-1}), TGB=total gross benefit (ETB ha^{-1}), TVC=total cost that vary (ETB ha^{-1}), NB=net benefit (ETB ha^{-1}).

Conclusions and Recommendations

N2 fixation by leguminous crops is a relatively low-cost alternative to N fertilizer for small-holder farmers in developing countries. N2 fixation in faba bean (*Vicia faba* L.) is affected by P fertilization and inoculation. The present study was conducted with the objectives of evaluating the effectiveness of different commercial and new rhizobia strains and to evaluate the effect of phosphorus fertilization on nodulation and grain yield of faba bean. The analysis of variance showed that seed yield exhibited a significant response to the treatments. In 2016/7, significantly the highest seed yield (2537 kg ha^{-1}) was observed with combined application of EAL-110 with 10kg ha^{-1}. The lowest seed yield (1931.6 kg ha^{-1}) was observed from the control plot. In 2017/18, significantly the highest seed yield was observed with inoculation of the seed of faba bean with strain EAL 110 alone. The partial budget analysis indicated that the highest mean net benefit (43800.7 birr ha^{-1}) was obtained when EAL-110 *Rhizobium* strain was applied with 10 kg P ha^{-1}. Hence, *Rhizobium* inoculation with strain EAL-110 with 10 kg P ha^{-1} could be recommended for faba bean production at the experimental locations in Moretna Jiru district.

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