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Research Article

Effects of Rhizobium Inoculation and P Fertilizer Levels on Selected Soil Properties, Yield, and Yield Components of Faba Bean (*Vicia faba L.*): The Case of Abuna Gindeberat, West Shewa Zone, Ethiopia

Achalu Chimdi,[1] **Dereje Negasa**,[1] **and Girma Chala**[2]

[1]*Ambo University, Department of Natural Resources Management, Ambo, Ethiopia*
[2]*Holeta Agricultural Research Center, Holeta, Ethiopia*

Correspondence should be addressed to Achalu Chimdi; achaluchimdi@yahoo.com

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Poor soil fertility status and inappropriate agronomic practices are the major factors for low crop productivity like legumes. Thus, the experiment was conducted to evaluate the effect of the P fertilizer rate and rhizobium inoculation on selected soil properties and yield of faba bean. In order to achieve this objective, a field experiment was laid out in a randomized complete block design in a factorial arrangement with replication. The treatments consisted of five P levels (0, 23, 46, 69, and 92 kg P_2O_5 ha^{-1}) and two rhizobium inoculants (Fb_{17} and Fb_{18}). Faba bean (Moti variety) was used as the test crop. Soil samples were collected before and after planting for laboratory analysis. All soil and agronomic data were subjected to the analysis of variance (ANOVA) using statistical analysis software version 9.2. The main effect of strain positively improved soil porosity, but soil bulk density was negatively influenced. Soil chemical parameters such as organic carbon, total N, available P, available sulfur, Ca, Mg, and K were positively influenced. The interaction effects of the P fertilizer rate and rhizobium inoculation significantly influenced organic carbon, total N, available P, and yield parameters (pod per plant, numbers of nodules per plant, biomass yield, straw yield, and grain yields). The combined application of 69 kg P_2O_5 ha^{-1} and Fb_{18} rhizobium inoculants gave the highest grain yield (4.4 t ha^{-1}) of faba bean. Thus, the integrated application of strain and P_2O_5 fertilizer improved soil fertility and faba bean crop yield. Therefore, reducing soil fertility constrains of the soils through the integrated application of strain and P_2O_5 fertilizer could be a possible option to reduce the yield gap seen between smallholder farmers and experimental fields. So as to maintain soil fertility and sustain faba bean crop production, farmers of the study area are advised to make integrated use of strain type Fb_{18} and P_2O_5 fertilizer at 69 kg/ha^{-1} with appropriate agronomic practices.

1. Introduction

Faba bean is one of the oldest crops in the world most probably domesticated in the late Neolithic period [1]. Faba bean is sometimes referred to as broad bean, horse bean, tic bean, or field bean [2]. Globally, it is the third most important cool-season food legume after chickpea and field pea with concentrated in nine major agro-ecological regions. In Ethiopia, faba bean is grown largely by subsistence farmers, during the cool season (June to September) [3]. In the 2014/2015 cropping season, out of a total grain crop area, 12.41% (1,558,442.04 ha) was under pulses. From this area, faba bean took up 3.53% (about 443, 074.68 ha) of the grain crop area. In terms of production, pulse contributed 9.88% (about 2.672 million tons) the grain production. Among pulses, faba bean accounted for 31.4% (0.84 million metric tons).

Agricultural productivity in the areas is declining due to the loss of fertility, which is caused by soil erosion and poor land management, and the productivity of the crops under smallholder farmers is not more 1.89 t ha^{-1} [4]. Among biotic categories, declining soil fertility and low pH (acidity) are the most determinant for low productivity of the most crops [5]. Farmers in the study area used crop rotation practice and fallow farming system to maintain the soil fertility of the land and have been applying inorganic fertilizer such as DAP and urea at a rate of its power. The main means of livelihood in the district are agriculture, which is based on mixed farming by the small landholders. Agriculture in the areas is predominantly rain-fed, and the amount, reliability, and distribution of rainfall are important determinants for crop yield. Majority of the farmers are depending on cereals and pulses.

Strain application in general can supply balanced nutrients for crop throughout a growing season and improve the quantity and quality of crops while at the same time enhances and sustains soil fertility particularly if applied together with chemical fertilizer. However, the present blanket fertilizer recommendation did not consider the integrated soil fertility management in the study area. Thus, it is important to have sufficient knowledge and evidence to find the best management alternatives that can solve location-specific nutrient problems and can supply crop nutrient requirement that is environmentally friendly and economically easy to buy by farmers. Therefore, the study was aimed to fill the gap regarding the combined use of strain and P_2O_5 fertilizer in enhancing soil fertility and increasing faba bean production under Nitisol condition of the Abuna Gindeberat district

2. Materials and Methods

2.1. Description of the Study Area. The experiment was conducted at Abuna Gindeberat district, Mandida sole kebele, which is located at a distance of 176 km from Finfine within Oromia Regional National State in West Shewa zone (Figure 1). The study area is situated at the latitude of 10°64′60″–10°54′67″ North, longitude of 38°69′25″E–38°89′18″E, and altitude of 2400 m.a.s.l.

2.2. Climate and Topography. Abuna Gindeberat district is characterized into two agro-ecology zones: midland (32%) and lowland (68%). The place has a mean minimum temperature of 10°C and mean maximum temperature of 30°C and the district has a uni-model rain fall pattern with an average annual rainfall of about 800–1400 mm and the altitude of the area is 2500 m.a.s.l and the district enjoys good weather condition including timely adequate rainfall.

2.3. Treatments and Experimental Design. The experiment was laid out in a randomized complete block design (RCBD) with factorial arrangement and replicated three times. The treatments consist of five rates of P_2O_5 fertilizer (0, 23, 46, 69, and 92 kg ha^{-1}) and isolates of rhizobium inoculants (Fb_{17} and Fb_{18}); the recommended rate of P_2O_5 and strain are 500 gm and 46 kg P_2O_5 ha^{-1} respectively. Moti variety of faba bean was used for trial. Each plot was $3.0\ m \times 2\ m = 6\ m^2$. The spacing between blocks and plots was 1.0 m and 0.5 m, respectively. Each plot has 8 rows spaced 40 cm apart, and the spacing between plants within row was 10 cm. One outer most row on each side of the plot and two plants (20 cm) on each end of rows was considered border. One row next to the border rows on any side was used for destructive sampling. The net plot will consist of 4 central rows of 2 m length and 1.6 m width, and each was used for data collection and measurements.

2.4. Experimental Procedures and Field Management. The experiment was conducted at Abuna Gindeberat, Mandida sole kebele. The experimental field was ploughed using oxen-drawn three times according to farmers' conventional farming practices. The first, second, and third plough were performed at the end of May, middle of June, and end of June before planting the crop, respectively. The gross plot size was $2.0\ m \times 3.0\ m$. The total area of the trial site was $269.5\ m^2$, and the net plot size was $1.6\ m^2$ by $2\ m^2$ ($3.2\ m^2$). The blocks were separated by a 1-m-wide open space, whereas the plots within a block were separated by a 1.0-m space from each other. The plots were leveled manually. Before planting, the seed was mixed with rhizobium until all coating attained and spread on flat plywood under shade and allowed to air for 30 minutes, and then, the phosphorous fertilizer was applied at different rates, and dried seeds of faba bean were planted by hand at 40-cm inter- and 10-cm intraplant spacing by planting two seeds per hill on 29 June accommodating eight rows per plots.

2.5. Soil Sample and Collection Techniques. Representative soil samples to a depth of 0–20 cm were collected before and after planting in a diagonal pattern from five spot of each block using an auger. The composite soil samples were air-dried, crushed, and passed through 2-mm sieve and mixed thoroughly following a standard procedure and analyzed for selected soil physical and chemical parameters except for total nitrogen and organic carbon in which 0.5-mm sieve was used for the determination of organic carbon (OC) described by the oxidation method [6], and the micro-Kjeldahl digestion, distillation, and titration procedure were used for the determination of total nitrogen (N) as described by [7]. Selected soil physical and chemical parameters were analyzed at the Holeta Agricultural Research Center of Soil and Plant Analytical Laboratory.

2.6. Analysis of Selected Soil Physicochemical Properties. The particle analysis was carried out using the hydrometer method [8]. Bulk density of undisturbed soil sample was determined using a core sampler [9, 10], and average soil particle density ($2.65\ g\ cm^{-3}$) was determined for estimating the total soil porosity. Soil pH was measured from soil suspension of 1 : 2.5 (weight/volume) soil-to-water ratio using a digital pH meter. Soil organic carbon was determined using the method described by [6]. Soil organic matter was calculated from organic carbon using the formula: $OM = 1.724^{*}\%OC$. Total nitrogen was determined using the modified Kjeldahl method as described by [7]. Available P was determined using the Bray II method [11],

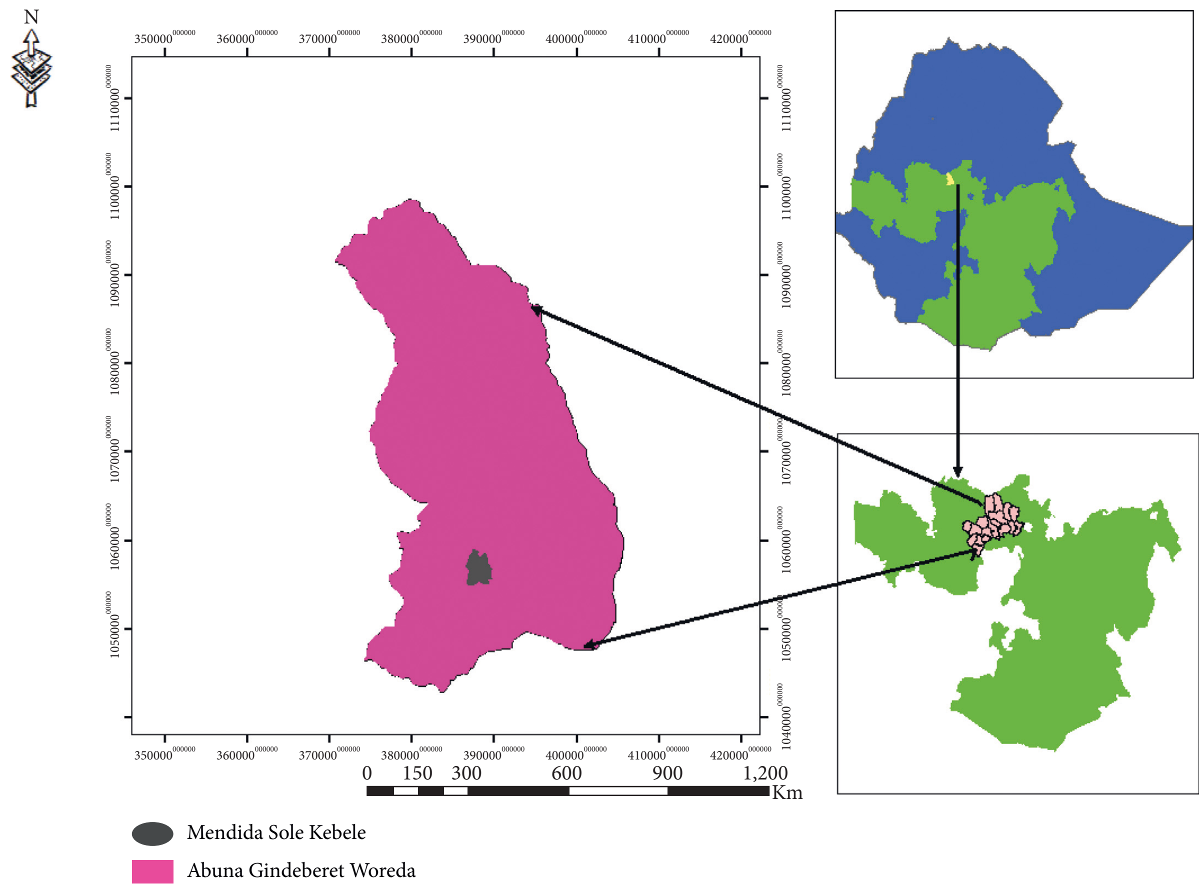

Figure 1: Location map of the study area.

and the P extracted was measured by a spectrophotometer. Exchangeable bases (Ca, Mg, K, and Na) were determined after extracting the soil samples using ammonium acetate (1 N NH_4OAc) at pH 7.0. Exchangeable Ca and Mg in the extracts were analyzed using an atomic absorption spectrophotometer, while Na and K were analyzed by a flame photometer [10, 12]. Exchangeable acidity (Al and H) were determined from a neutral 1 N KCl extracted solution through titration with a standard NaOH solution.

Table 1: Soil physical properties of the experimental site before planting.

Physical properties	Value	Rate	Reference
Soil textural class (%)	—	Clayey	[14]
Clay (%)	68.5	High	
Silt (%)	18.75	Low	
Sand (%)	12.75	Low	
Bulk density (gcm^{-3})	1.3		
Total porosity (%)	42.6		

2.7. Statistical Analysis. The data collected on different parameters were statistically analyzed using PROC ANOVA (SAS) program. After performing ANOVA, the differences between the treatment means were compared by LSD test at 5% level of significance [13].

3. Results and Discussion

3.1. Selected Soil Properties of Experimental Site Before Planting. The laboratory results of the selected physical properties before sowing are presented in Table 1. The results indicated that the soil has 68.75% clay, 18.75% silt, and 12.75% sand content. The results indicated that soil bulk density and total porosity were 1.3 g cm^{-3} and 42.6% (Table 1). Moreover, the value of total porosity was in the ideal range for health root growth. This indicates that porosity and bulk density values of the surface soil were in an acceptable range for faba bean crop production [14]. Similarly, the chemical properties of soils before planting are presented in Table 2. The soil pH (5.31) was strong acid on the basis of the pH range proposed by [14]. At this pH value, P is fixed to soil surfaces of Fe and Al oxides and hydrous oxide, which are not readily available to plants [14, 18, 19]. However, [2] indicated that faba bean plants can grow well in the pH range between 4.5 and 9.0 pH. Therefore, the pH of the experimental soil is suitable for faba bean production.

The organic C content (1.34%) of the study site was categorized in a low range as per rating by [14]. Similarly, the low available P (7.98 ppm) [20] and very low available S (1.21 ppm) and medium total N were categorized as per rating suggested by [15, 16]. The low content of soil organic C, medium total N, and available P contents indicated insufficient fertility status of the soil (Table 2). This could be

Table 2: Soil chemical properties before planting.

Chemical properties	Value	Rates	Reference
Soil (pH)	5.29	Strong acid	[15]
Total N (%)	0.15	Medium	[15]
Available P (ppm)	7.98	Low	[16]
Exchangeable K (cmol (+) kg^{-1})	0.42	Medium	[17]
Exchangeable Ca (cmol (+) kg^{-1})	10.75	High	[17]
Exchangeable Mg (cmol (+) kg^{-1})	3.11	High	[17]
Exchangeable Na (cmol (+) kg^{-1})	0.20	Low	[17]
Exchangeable acid (cmol (+) kg^{-1})	0.98	—	—
Organic C (%)	1.34	Low	[15]
Sulfur (S) (ppm)	1.21	Very low	[15,16]

due to continuous cultivation and lack of incorporation of enough organic materials to soils.

3.2. Effect of Rhizobium Strain and P Fertilizer on Soil Physical Properties. The analysis of variance indicated that the main effect of rhizobium strain significantly ($p < 0.05$) affected soil bulk density and total porosity (Table 3). However, the main effect of P fertilizer as well as their interaction did not significantly ($p \geq 0.05$) affected by bulk density and total porosity.

3.3. Bulk Density and Total Porosity. Bulk density is an important physical property, which could affect root developments of plants. Application of different types of rhizobium strains negatively influenced soil bulk density (Table 3). A decrease in the value of the soil bulk density could be observed due to the application of strain Fb_{18}. Accordingly, the lowest (1.22 g cm^{-3}) and the highest (1.28 g cm^{-3}) soil bulk densities were observed in the plot treated with Fb_{18} and Fb_{17} plots, respectively (Table 3). The main reason for the reduction in the bulk density after the application of strain Fb_{18} might be due to the bulk density decreasing effect of the strain, which could be evidenced from the negative correlation ($r = -0.67$) between the soil organic matter and bulk density. In line with this, [21] reported that the application of strain significantly decreased the soil bulk density. The total porosity had showed consecutive increment from 42.7 to 56.2% as that of P fertilizer increased from 0 to 92 kg ha^{-1} with rhizobium strain Fb_{18}. Accordingly, a maximum total porosity of the soil (56.2%) was observed in the plot that was treated with rhizobium strain Fb_{18} and P_2O_5 at a rate of 92 kg ha^{-1} followed by 69 kg ha^{-1} P fertilizer rate with similar strain, which was statically at par with the highest total porosity. Highest values of total porosity obtained from the plots treated with 92 kg P ha^{-1} and rhizobium strain Fb_{18} corresponded to the highest amount of organic C contents and the lowest bulk density values for the plot. A study by [22] also reported that the addition of strain types at a higher rate significantly improved the porosity of soil and other soil physicochemical properties when compared to the control plot.

3.4. Effect of Rhizobium Strain and P Fertilizer on Soil Chemical Properties. The soil pH was varied from 5.31 to 5.54, and it is in the category of strong acidic (Table 3). This value of soil pH increased as compared to the presowing soil pH. The highest soil pH (5.54) was recorded from the combination of 92 kg ha^{-1} P_2O_5 fertilizer level and Fb_{18} rhizobium inoculants, while the lowest pH (5.31) was recorded from the combination of 0 kg ha^{-1} P_2O_5 fertilizer level and Fb_{17} rhizobium inoculants (Table 3). The main effects of rhizobium inoculants and the effect of P fertilizer rate were significantly ($p < 0.05$) affected by soil pH.

Table 3: Main effect of strain and P fertilizer on bulk density, total porosity, and pH of soil.

Rhizobium strain	Bulk density	Porosity (%)	Soil pH
Fb_{17}	1.27^a	48.8^b	5.48^b
Fb_{18}	1.22^b	51.8^a	5.51^a
Mean	1.24	50.3	5.49
LSD (5%)	0.016	1.27	0.69
P level (kg/ha)			
0	1.28	48.8	5.29^b
23	1.27	49.7	5.48^{ab}
46	1.24	50.7	5.51^{ab}
69	1.23	50.9	5.53^a
92	1.20	51.5	5.54^a
Mean	1.24	50.32	5.49
LSD (5%)	NS	NS	0.069
CV (%)	1.41	3.2	1.22

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \leq 0.05$) according to LSD, FB = faba bean, CV = coefficient of variation, NS = not significant, LSD = least significant differences.

3.5. Total Nitrogen, Soil Organic Carbon, and Available Phosphorous. The effect of rhizobium strain and P fertilizers as well as their interaction effect highly and significantly ($p < 0.05$) affected total nitrogen of the soil (Table 4). Total N was in the range of 0.155 to 0.264% after the application of different rates of P fertilizer and different types of rhizobium strains. The highest value of soil total N (0.264%) was recorded from plots treated with rhizobium strain Fb_{18} + 92 kg ha^{-1} P fertilizer, and the lowest value of total N (0.155%) was recorded from zero P fertilizer and strain Fb_{17} treatment. It was observed that the content of soil total N increased by about 42.31% over the control plot for this dose. This substantial increase in total N could have been caused by quick action of rhizobium strains inoculation in improving soil nitrogen concentration. The highest total N obtained from the application of rhizobium strain Fb_{18} + 92 kg ha^{-1} P fertilizer might be attributed to N fixed biologically by microorganism. As the amount of organic carbon increased in the soil through the application of strain fertilizer, total nitrogen also increased. In the present study, rhizobium inoculation altered the chemical properties of rhizosphere whereby most of the mineral elements were increased in rhizosphere soils of inoculated soybean over the control. As reported by [23], rhizobium inoculations altered most of the chemical properties of the rhizosphere soil of soybean in this study. The rhizosphere soil chemical properties such as pH, OC, and macro- and micronutrients

Table 4: The interaction effect of rhizobium inoculation and P fertilizer on soil total N.

Total nitrogen (%)					
	P_2O_5 kg ha^{-1}				
Rhizobium inoculants	0	23	46	69	92
Fb_{17}	0.155^{e}	0.20^{d}	0.214^{cd}	0.226^{c}	0.262^{a}
Fb_{18}	0.16^{e}	0.21^{cd}	0.238^{b}	0.258^{a}	0.264^{a}
LSD (5%)			0.015		
CV (%)			4.11		

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \leq 0.05$) according to LSD, FB = faba bean, CV = coefficient of variation, LSD = least significant difference.

Table 5: The interaction effect of rhizobium inoculations and P fertilizer on soil organic carbon.

Soil organic carbon (%)					
	P_2O_5 kg ha^{-1}				
Rhizobium inoculants	0	23	46	69	92
Fb_{17}	1.32^{e}	1.44^{cd}	1.45^{cd}	1.47^{bc}	1.51^{ab}
Fb_{18}	1.45^{cd}	1.42^{d}	1.45^{cd}	1.45^{cd}	1.54^{a}
LSD (5%)			0.04		
CV (%)			1.73		

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \leq 0.05$) according to LSD, FB = faba bean, CV = coefficient of variation, LSD = least significant differences.

(N, P, Ca, Mg), and the supply of P fertilizers significantly increased the rhizosphere content of macronutrients. Effect of P fertilizer and their interaction of strain phosphorous fertilizer significantly ($p < 0.05$) affected by soil organic C, but the main effects of rhizobium strain did not significantly ($p \geq 0.05$) influence organic C of soil after harvesting (Table 5). The highest soil C (1.54%) was obtained from the application of maximum dose of P fertilizer (92 kg ha^{-1}) along with rhizobium strain Fb_{18}, while the lowest value (1.32%) was recorded from zero P fertilizer and strain Fb_{17} treatment (Table 5). The increment of soil organic carbon over the control by 14.3 percent over control could be due to an increase in the soil organic carbon content with the addition of the best strain types. The increase in organic C might be attributed to better root growth and deposition of organic materials in the first cropping season. Similar findings were reported by [24] suggested that organic carbon significantly increased in the rhizosphere soil of rhizobium inoculated soybean over the control. However, these findings on organic C in the rhizosphere differed from that of [25] who found that rhizobium inoculation decreased the soil pH and the soil organic C. They urged that a decrease in organic C may have been attributed by increased microorganisms, which hasted the decomposition of organic C in the rhizosphere.

Soil available P is the most common plant growth-limiting nutrient in the tropical soils next to N. As the result of analysis showed, the highest (12.65 ppm) soil available P was obtained from plots that applied with the combination

Table 6: Interaction effect of rhizobium inoculations and P fertilizer on available P.

Available P (ppm)					
	P_2O_5 kg ha^{-1}				
Rhizobium inoculants	0	23	46	69	92
Fb_{17}	8.02^{d}	8.32^{d}	9.75^{c}	10.61^{bc}	12.05^{a}
Fb_{18}	8.01^{d}	8.34^{cd}	10.39^{bc}	11.08^{b}	12.65^{a}
LSD (5%)			0.84		
CV (%)			4.96		

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \leq 0.05$) according to LSD, FB = faba bean, CV = coefficient of variation, LSD = least significant differences.

Table 7: Effect of rhizobium strain and P fertilizer on exchangeable acidity and basic cations.

Rhizobium strain	Exchangeable acid	Exchangeable bases (cmol (+) (kg^{-1})			
	cmol (+) (kg^{-1})	K	Ca	Mg	Na
Fb_{17}	0.86^{b}	0.51^{b}	11.26^{a}	3.35^{b}	0.0254
Fb_{18}	1.093^{a}	0.56^{a}	12.68^{b}	3.74^{a}	0.0254
LSD (%)	0.046	0.031	0.39	0.26	NS
CV (%)	9.2	7.56	6	9.85	8.34
P_2O_5(kgha^{-1})					
0	1.088	0.52	11.21	3.52	0.0248
23	1.094	0.53	11.26	3.27	0.0248
46	1.102	0.537	11.32	3.51	0.0255
69	1.112	0.54	11.46	3.69	0.0257
92		0.56	11.89	3.71	0.0247
LSD (%)	NS	NS	NS	NS	NS
CV (%)	5	0.057	1.25	0.46	1.03

Means followed by the same letter within the same column are not significantly different ($p < 0.05$) according to least significant difference, CD = critical difference, NS = nonsignificant, FB = faba bean.

of the maximum rate of the P fertilizer (92 kg ha^{-1}) and strain Fb_{18}, while the lowest value (8.01 ppm) was recorded from the 0 kg ha^{-1} P rate and strain Fb_{17}-treated plot. The improvement in available P recorded from maximum dose P and strain might be due to release of P from external and capacity of rhizobium inoculation strain in reducing the inorganic P sorption capacity of the soil besides converting nonlabile P to labile P of native source under acidic nature of soil. The positive correlation ($r = 0.76$) between P and organic matter can be taken as evidence for the improvement of available P (Table 6).

3.6. Exchangeable Bases and Acidity. The analysis of data indicated that the effect of strain significantly ($p < 0.05$) affected soil exchangeable Ca, Mg, and K (Table 7), but the effect of phosphorous fertilizer as well as their interaction did not significantly ($p \geq 0.05$) influence exchangeable K, Ca, and Mg (Table 7). Nevertheless, exchangeable Na was not significantly ($p \geq 0.05$) affected by either of them. Improvement in the status of soil exchangeable Ca, Mg, and K was obtained as a result of application of rhizobium inoculation strain. Improvements in the concentrations of Ca, Mg, and K in the soil were observed with types of faba bean strain Fb_{18} applied. Thus, maximum mean soil exchangeable bases (Ca, Mg, and K) were recorded from the application of strain Fb_{18}, while the lowest values of Ca, Mg, K were obtained from control. The increase in exchangeable base values above the control might be due to increased soil pH, which favored the availability of most plant nutrients. Increased availability of nutrients in the rhizosphere soil provides normal growth of plants and eventually increased yield. Normally, if there is low soil pH, the soil is acidic, which results in poor plant growth and development as most of plant nutrients become unavailable for plants. Likewise, [26, 27] also observed improvement in these exchangeable bases because rhizobium produces Fe career compound called siderophores, which tends to increase the Fe content in the rhizosphere soil. Also, the decaying cells of microorganisms release nutrients and make them available in the rhizosphere soil. Therefore, application of appropriate strain to a low-fertility status of acidic soil can enhance concentrations of basic cations in soil solution. The main effect of rhizobium inoculants strain significantly ($p < 0.05$) affected exchangeable acidity, but the effect of phosphorous fertilizer and the interaction of strain and phosphorous fertilizer did not significantly influence the exchangeable acidity of the soil (Table 7). Application of strain in soil contributed to the improvement of soil acidity. The present finding exhibited that exchangeable acidity decreased by about 45.38 percent when strain Fb_{18} types were applied relative to presowing soil analysis. Altered rhizosphere in soil pH following application of strain could be resulted from the release of organic acids, which in turn led to a decrease in exchangeable acidity of the soil through chelation. This decrease in exchangeable acidity might also be ascribed to the increase in the replacement of Al by Ca in the exchange site and by the subsequent precipitation of Al to Al $(OH)_3$ since strain has a liming effect on soil [19].

3.7. Effects of Rhizobium Inoculation and P Fertilizer Rate on Yield Component of Faba Bean. The analysis of variance indicated that the main effects of P fertilizer were highly and significantly ($p < 0.05$) affected days of 50% flowering. However, the main effects of strain and their interaction were not significantly ($p \geq 0.05$) affected days of 50% flowering (Table 8). The maximum (69.1) number of days to flowering was observed at the rate of 0 kg P_2O_5 ha^{-1}, while the minimum number of days to flowering was (60.5) observed at 92 kg P_2O_5 ha^{-1}. Increasing rates of P from 0 to 92 kg ha^{-1}, accelarated by 13 percent. This may be due to the requirements of flowering times, which mostly depends on external nutrient. The number of days of 50% pod setting was significantly ($p < 0.05$) affected by the main effect of strain and P fertilizer levels, but the interaction effect of P application rate and rhizobium inoculants show nonsignificant (Table 8). It is evident from the results seed inoculation with both Fb_{17} and Fb_{18} inoculant shows 78 and 80.5 days, respectively, of pod setting from sowing. Also for phosphorus, the maximum (83.3 days) number of days of 50% pod setting was observed at 0 kg P_2O_5 and the minimum number of days of pod setting was (76) days observed at 92 kg P_2O_5 ha^{-1}. This indicates that the number of days to physiological maturity was decreased with an increasing rate of P_2O_5 fertilizer. This might be due to the high P rate with the increase in the P fertilizer rate, which contributed to the shortening of the number of days to physiological maturity.

Table 8: Main effects of strain and P fertilizer on 50% days to flowering, pod setting, and 90% day to physiological maturity.

Rhizobium strain	Days of 50% flowering	Days of 50% pod setting	90% maturity
Fb_{17}	64.9	80.5^{a}	124.9
Fb_{18}	64.5	78^{b}	125
Mean	64.7	79.2	124.95
LSD (5%)	NS	1.9	NS
P level (kg/ha)			
0	69.17^{a}	83.3^{a}	130.7^{a}
23	66.5^{b}	79^{bc}	127.8^{b}
46	64.6^{c}	76.7^{c}	125^{c}
69	62.8^{d}	81.1^{ab}	121.8^{d}
92	60.5^{e}	76.2^{c}	119.5^{e}
Mean	64.7	79.26	124.97
LSD (5%)	1.09	3.03	1.83
CV (%)	1.41	3.2	1.22

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \leq 0.05$) according to LSD = least significant differences, FB = faba bean, CV = coefficient of variation, LSD = critical range, P = phosphorous.

3.8. Days of 90% Maturity. Main effect of P_2O_5 rates ($p < 0.05$) affected the physiological maturity of faba bean (Table 8). However, sole application of strain and their interaction did not significantly ($p \geq 0.05$) affected 90% physiological maturity of faba bean. Accordingly, the highest 130.7 days to maturity were obtained from the control plot and the minimum 119.5 days to maturity were recorded from the 92 kg P_2O_5 ha^{-1} fertilizer rate. Early maturity in response to the increasing rate of P_2O_5 attributed to the adequate nutrients supplied to soil from atmosphere by biological nitrogen fixation and P_2O_5 fertilizer that may have led to quick maturity.

3.9. Effects of Rhizobium Inoculant and P Fertilizer on Growth Parameters. From the analysis of variance, all the main effects of rhizobium strain and P fertilizer showed significant ($p < 0.05$) for faba bean plant height at physiological maturity stage, but the interaction of both rhizobium strain and P fertilizer were insignificant ($p \geq 0.05$) for faba bean plant height (Table 9). The highest plant height for strain was 142.9 cm at Fb_{18} and 158.cm at 92 kg P_2O_5 ha^{-1}. The lowest plant height for strain was 135.6 cm at Fb_{17} strain and 117 cm at 0 kg P_2O_5 ha^{-1}. As the level of P_2O_5 fertilizer increases from 0 to 92 kg ha^{-1}, the plant height increases by 26.4%. This could be due to P_2O_5 fertilizer, which has a great contribution to the vigorous vegetative growth and development by promoting growth and photosynthetic activity. Also, this might be the optimum rate to trigger an increase in

Table 9: The main effects of rhizobium inoculation and P fertilizer levels on plant height.

Rhizobium inoculants	Plant height
Fb_{17}	135.7^{b}
Fb_{18}	142.9^{a}
Mean	139.3
LSD (5%)	3.2
P level (kg/ha)	
0	117^{e}
23	124.8^{d}
46	136^{c}
69	152.6^{b}
92	158.6^{a}
Mean	139.3
LSD (5%)	5.1
CV (%)	3.07

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \le 0.05$) according to least significant difference (LSD), PH = plant height, CV = coefficient of variation, LSD = critical range, FB = faba bean.

Table 10: Interaction effects of rhizobium inoculation and P fertilizer rate on pods per plant.

	Pods per plant P_2O_5 kg ha^{-1}				
Rhizobium inoculants	0	23	46	69	92
Fb_{17}	10.6^{g}	12.6^{fg}	16.13^{de}	20^{bc}	22.8^{ab}
Fb_{18}	12.06^{fg}	13.7^{ef}	17.9^{cd}	25.2^{a}	24.8^{a}
LSD (5%)			2.8		
CV (%)			5.6		

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \le 0.05$) according to LSD, CV = coefficient of variation, LSD = least significant differences, FB = faba bean.

Table 11: Interaction effects of rhizobium inoculation and P fertilizer rate on number of nodule per plants.

	Nodules per plant P_2O_5 kg ha^{-1}				
Rhizobium inoculants	0	23	46	69	92
Fb_{17}	33.7^{e}	$36.9d^{e}$	47.8^{c}	55.6^{b}	67.4^{a}
Fb_{18}	34.3^{e}	44^{cd}	58.6^{b}	70.1^{a}	73.9^{a}
LSD (5%)			7.2		
CV (%)			5.6		

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \le 0.05$) according to LSD, FB = faba bean, CV = coefficient of variation, LSD = least significant differences.

Table 12: The main effects of RI and P fertilizer rates on number of seeds per pods and thousand seed weight.

Rhizobium strain	No. of seeds per pods	Thousand seed weight (TSW)
Fb_{17}	3.4^{b}	689.2^{b}
Fb_{18}	4.37^{a}	713.5^{a}
Mean	3.8	705.8
LSD (5%)	0.9	1.47
P level (kg/ha)		
0	2.8^{c}	625.1^{e}
23	3.75^{b}	666.8^{d}
46	4.08^{ab}	707.3^{c}
69	4.33^{a}	735.3^{b}
92	4.46^{a}	772.1^{a}
Mean	3.8	701.37
LSD (5%)	0.56	18.9
CV (%)	12.18	1.12

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \le 0.05$) according to LSD, FB = faba bean, CV = coefficient of variation, LSD = critical range.

the plant height with a unit increase in the phosphorus rate as deduced from the control plots and better development of root system and nutrient absorption. Similarly, this result agreed with the result of [28], which affirmed that the application of rhizobium stains could increase the plant height of faba bean.

3.10. Numbers of Pods per Plants. The analysis of variance indicated that the main effects of strain and P fertilizer levels highly and significantly ($p < 0.05$) affected the number of pods per plants. In addition, their interaction was significant ($p < 0.05$) (Table 9). Faba bean yields are generally dependent upon the number of pods per plant. The maximum number of pods per plant observed for the plot treated with phosphorous fertilizer levels at 69 kg P ha^{-1} and strain Fb_{18} was 25.2, while the minimum number of pods per plant was 10.6 recorded at 0 kg P ha^{-1} and strain Fb_{17} (Table 10). The result of this study is in agreement with the result of [29] who indicated that all applied P fertilizer rates significantly increased pods per plant over the control and significantly higher number of pods per plant was recorded with P rates of 20 kg ha^{-1} over rest of the levels.

3.11. Numbers of Nodules per Plants. The analysis of variance indicated that the main effects of strain and P fertilizer significantly ($p < 0.05$) affected the number of nodules per plants. Similarly, the interaction of the phosphorus fertilizer and rhizobium inoculation also showed significance on number of nodules per plants (Table 11). The maximum number of nodules per plant for 73.9 was recorded from the plots treated by strain Fb_{18} with 92 kg P ha^{-1}, while the minimum nodules per plant (33.7) were obtained from 0 kg P ha^{-1} along rhizobium inoculation with Fb_{17} that shows the differences between both strain types by 28.5 percent. This result implies that inoculation of those strains may best suit in the study area to bust the nodule number.

The result is in line with the findings of Refs. [30, 31], which reported that the inoculation of rhizobium strain to faba bean significantly increased the nodule number.

3.12. Effects of Strain and P Fertilizer on Yield Component. The main effects of P fertilizer rate and the effect of rhizobium strain significantly ($p < 0.05$) affected the number of seeds per pods. However, their interaction of $s^* p$ and the effect of strain significantly ($p \ge 0.05$) affected number of seeds per pods of faba bean (Table 12). The highest number

Table 13: Interaction effects of rhizobium inoculation and P fertilizer rate on dry biomass yields.

	Total biomass yield (t ha^{-1}) P_2O_5 kg ha^{-1}				
Rhizobium inoculants	0	23	46	69	92
Fb_{17}	5.1^e	6 d^e	$6.2d^e$	7.5^c	9.5^{ab}
Fb_{18}	5.6^e	6.6^{cd}	9.1^b	10.6^a	10.2^{ab}
LSD (5%)			1.2		
CV (%)			5.6		

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \leq 0.05$) according to LSD, FB = faba bean, CV = coefficient of variation, LSD = least significant differences.

Table 14: Interaction effects of rhizobium inoculations and P fertilizer rate on grain yields.

	Grain yield (t ha^{-1}) P_2O_5 kg ha^{-1}				
Rhizobium inoculants	0	23	46	69	92
Fb_{17}	1.6^i	2.4^g	3^e	3.3^{de}	3.6^c
Fb_{18}	1.7^h	2.7^f	3.4^d	4.4^a	4.1^b
LSD (5%)			0.24		
CV (%)			5.6		

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \leq 0.05$) according to LSD, FB = faba bean, CV = coefficient of variation, LSD = least significant differences.

of seeds per pods (4.4 and 4.3) was obtained from the plot treated by 92 kg ha^{-1} P fertilizer rate, which was statistically at par with 69 kg ha^{-1} and 46 kg ha^{-1} P and strain Fb_{18}, respectively, whereas the minimum (2.8) number of seeds per pods was recorded from nil P fertilizer plots and for strain 3.4 at the soil treated with rhizobium strain Fb_{17}. The possible reason for an increase in the number of seeds/pods with an increase in the P rate might be P fertilizer for nodule formation, protein synthesis, fruiting, and seed formation, and strain can be made to the availability of growth-limiting primary nutrients such as nitrogen in sufficient amount in the soils, which in turn promotes vegetative growth.

3.13. Thousand Seeds Weight. The analysis of variance indicated that the main effect of P fertilizer rate and strain highly and significantly ($p < 0.05$) affected thousand seed weights of faba bean but not their interaction of both P and rhizobium strain (Table 12). The maximum weights of thousand seeds (772.2gm and 713.47 gm) were recorded from the plots treated by 92 kg P ha^{-1} and the plots treated by rhizobium strain Fb_{18}, respectively, while the minimum weights of thousand seeds (625.1 gm and 689.2 gm) were obtained from the zero P fertilizer and for strain Fb_{17}, respectively. These results may be gained from this work could be attributed the effect of the grain filling ability of nitrogen through nitrogen biological fixation and contribution of P fertilizer on seed filling.

3.14. Total Biomass. The above ground dry biomass yield was highly and significantly ($p < 0.05$) affected by main effects of strain and P fertilizer rates. The same result is that the interaction of main effects of phosphorous with rhizobium strain significantly affected the total biomass yield of faba bean (Table 13). The highest (10.6 t ha^{-1}) dry biomass of faba bean was obtained from plots treated by 92 kgP ha^{-1} fertilizer with rhizobium inoculants (Fb_{18} strain). The lowest (5.1 t ha^{-1}) was obtained from zero P fertilizer along strain Fb_{17} plots treated. With increasing P fertilizer rates, the total biological yield also increased. This highest value of dry biomass over the control and strain alone might be due to the good response of faba bean crop to synergistic interaction effect of nutrients supplied by strain and P fertilizers, which are well observed through the synthesis of proteins, formation of new tissues, and over all vegetative growth of faba bean crop.

Table 15: Interaction effects of rhizobium inoculation and P fertilizer rate on straw yield.

	Straw yield P_2O_5 kg ha^{-1}				
Rhizobium inoculant	0	23	46	69	92
Fb_{17}	3.1^b	3.2^b	3.9^b	4.2^b	5.9^a
Fb_{18}	3.2^b	3.8^b	5.8^a	6.2^a	6.1^a
LSD (5%)			1.17		
CV (%)			5.6		

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \leq 0.05$) according to LSD, FB = faba bean, CV = coefficient of variation, LSD = least significant differences.

3.15. Grain Yield. The grain yields of faba bean were significantly ($p < 0.05$) affected by the interaction of main effects of phosphorous with rhizobium strain and with both main effects of strain and P fertilizer rates (Table 14). Analysis of variance indicated that the highest grain yield of faba bean (4.4 t ha^{-1}) was obtained from the application of 69 kg ha^{-1} P along with rhizobium inoculants Fb_{18} strain. However, the lowest grain yield of faba bean observed from the plots treated with zero kg ha^{-1} P and rhizobium strain Fb_{17} is 1.6 t ha^{-1}. This indicates that the application of strain Fb_{18} and 69 kg ha^{-1} P fertilizer can be taken as optimum for the maximum productivity of this crop in the study area. The lowest grain yield (1.6 t h^{-1}) was recorded from zero P fertilizer application with strain Fb_{17} plots. The application rhizobium strain Fb_{18} and 69 kg ha^{-1} P fertilizer increased grain yield by 63.7 percent than the plot treated by rhizobium strain Fb_{17} with O kg ha^{-1} P. These work results demonstrated that soil nitrogen is a limiting factor, and the existing rhizobium bacteria may not be able to supply nitrogen through biological nitrogen fixation. Thus, the grain yield could be strongly improved by means of inoculation or fertilization.

3.16. Straw Yield. Analysis of variance showed that the straw yield of faba bean was significantly ($p < 0.05$) affected by the

Table 16: The main effects of rhizobium inoculation and P fertilizer rates on harvest index.

Rhizobium strain	Harvest index
Fb_{17}	38.9^{b}
Fb_{18}	43.05^{a}
Mean	41.02
LSD (5%)	4.02
P level (kg/ha)	
0	35.4^{b}
23	42.4^{a}
46	42.9^{a}
69	43.2^{a}
92	39.1^{a}
Mean	41.02
LSD (5%)	6.6
CV (%)	11.4

Means followed by the same letter within the same column of the respective treatment are not significantly different ($p \le 0.05$) according to least significant differences, FB = faba bean, CV = coefficient of variation, LSD = critical range.

main effects of strain and P fertilizer and their interaction(Table 15). The highest mean straw yield (6.2 t ha^{-1}) was obtained from 92 kg ha^{-1} P fertilizer with rhizobium inoculants Fb_{18} strain. These results are statically at par with (92, 69, 46 kg P ha^{-1}) fertilizer combination with the same strain. The lowest straw yields (3.1 t ha^{-1}) were obtained from zero kg ha^{-1} P fertilizer with rhizobium strain Fb_{17}. The increase in the straw yield as result of main effect of strain and P fertilizer might be due to better performing of phosphorus, which plays a role in healthy plant growth, contributing to structural strength, crop quality, and seed production.

3.17. Harvest Index. Harvest index was significantly ($p < 0.05$) affected by the main effect of rhizobium strain and interaction of both treatments. However, the main effect of p was not significantly ($p \ge 0.05$) affected by the harvest index. The highest harvest index was recorded in response to the application of rhizobium strain Fb_{18} at 43.01 percent (Table 16). Significant difference was observed due to the application of mineral P fertilizer in which 69 kg P ha^{-1} application resulted in the highest mean harvest index (43.4), which was in statistical parity with 23, 46, and 92 kg P ha^{-1}. Furthermore, application of 30 and 40 kg P ha^{-1} resulted in significant increases in the harvest index over unfertilized treatment. The increase in the harvest index might have been mainly due to the availability of phosphorus to the plant.

4. Conclusions

The finding of the present study found that sole application of *Rhizobium* inoculation (Fb_{18}) to plots significantly affected that except bulk density and exchangeable acidity, strain type of Fb_{18}. In another way, plant height, maturity date, and thousand grain yields were also positively influenced by P_2O_5 fertilizer and rhizobium inoculant applied to the experimental plots. With the same manner, interaction effects of rhizobium inoculants plus P_2O_5 fertilizer brought a positive influence on soil chemical parameters (total nitrogen, available P, and organic carbon) and growth parameters (nodule per plant) and yield parameters (number of pods, biomass, straw and grain yields, seed per pods, and thousand seed weight). Combination of rhizobium inoculants (Fb_{18} and 69 kgP_2O_5 ha^{-1}) gave (4.4 t ha^{-1}) increased faba bean by 63.7% over control treatment, which is better improvement than Fb_{17} plus 69 kgP_2O_5 ha^{-1} fertilizer by about 25% for the same variety. But, grain yield of the crop was still low as compared to the global average and its potential yield. At the end from this finding, one can conclude that to get optimum, sustained long-lasting, and self-sufficient crop production, soil fertility has to be maintained. Thus, integrated application of appropriate strain and P_2O_5 fertilizers to strong acid soil had improved soil fertility and thereby increased faba bean crop yield. Moreover, reducing the soil fertility constraints of the study area through appropriate rhizobium inoculant types and P_2O_5 fertilizer could be one option to reduce the yield gap seen in smallholder farmers and experimental fields besides minimizing adverse environmental impact of inorganic N fertilizer by substituting biological nitrogen fixation, which is environmental-friendly.

Data Availability

The data used to support the results of this study are included within the manuscript, and any further information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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