

Research Article

Integrated Acid Soil Management for Growth, Nodulation, and Nutrient Uptake of Faba Bean (*Vicia faba* L.) in Lay Gayint District, Northwestern Highlands of Ethiopia

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Soil acidity is one of the forms of soil degradation affecting sustainable crop production adversely in the Ethiopian highlands. In order to contribute to soil acidity amelioration and crop productivity improvement on acid soils, an experiment was conducted to investigate the effects of lime, mineral P, FYM, compost, and rhizobium on growth, nodulation, and nutrient uptake of faba bean (*Vicia faba* L.) in cultivated acid soil under greenhouse conditions. Twenty treatments were tested in isolations as well as suitable combinations. The treatments were arranged in a completely randomized design with three replications. The results showed that application of 8 t FYM·ha⁻¹ + 30 kg P·ha⁻¹ + 5 t lime·ha⁻¹ produced significantly ($P < 0.001$) higher plant height (58.67 cm), number of branches (13.78) and leaves per plant (37.11), shoot dry weight (5.14 g per plant), tissue N (3.83%) and P (0.219) contents and uptakes, and soil N (0.28%) and P (7.61 mg·Kg⁻¹) after harvest. However, significant increases ($P < 0.001$) in nodule number (153.33) and nodule dry weight (131.33 mg per plant) were obtained due to application of 4 t FYM·ha⁻¹ + 15 kg P·ha⁻¹ + 10 t lime·ha⁻¹. The increased above-ground biomass, and nodulation could be due reducing soil acidity, and the supply of N, P, and other nutrients in FYM through mineralization. Therefore, combined use of lime, FYM, and P fertilizers could improve the growth characteristics, nodulation, and nutrient uptake of faba bean in acid soil of Lay Gayint district. However, the treatments should be tested in the field to verify the greenhouse results.

1. Introduction

Acid soils are found dominantly in South and North Americas, Asia, and Africa. They occupy about 40% of the total arable land area in the world [1]. Soil acidity and decline in soil fertility are forms of soil degradation adversely affecting sustainable crop production in the Ethiopian highlands, where the rainfall intensity is high and crop cultivation has occurred with reduced manure application, and removal of crop residue [2, 3]. In Ethiopia, soil acidity is one of the major limiting factors on productivity and long-term sustainability of faba bean [4].

The causes of soil acidity could be the type of parent materials from which the soil are formed, leaching of basic cations such as Ca²⁺, Mg²⁺, and K⁺, and continuous use of acid-forming mineral fertilizer sources such as urea (CO (NH₂)₂) and diammonium phosphate ((NH₄)₂ HPO₄) which produce hydrogen ion (H⁺) through oxidation of ammonium ion (NH₄⁺) to nitrate ion (NO₃⁻) [5]. The uptake of nutrients by plants also results in partitioning of acidity into the soil [6]. At pH less than 5.0, toxic levels of Al, H, and sometimes Mn, as well as deficiencies of P, Mo, Ca, Mg, and K may reduce plant growth on acid soils. In addition, beneficial activities of some microorganism species are reduced by soil acidity [7].

In acid soils, the growth and multiplication of rhizobium is impaired. This hampers the likelihood of successful nodulation during early plant growth, which is when the roots of the host plant can be infected [8]. The optimum soil pH for different species of rhizobium to work is different. For example, rhizobium *leguminosarum* bv. *viciae*, *Sinorhizobium meliloti*, and *Rhizobium leguminosarum* bv. *trifolii* mostly fixed atmospheric dinitrogen (N_2) when soil pH is around 6.5 [9]. In highly weathered acid soils of tropics and subtropics, P deficiency is a major constraint to crop production and P fertilizers need to be applied to obtain optimum plant growth and crop yields [2]. Of all nutrients, shortage of P has the biggest impact on legumes which generally rely on atmospheric N_2 fixation for N nutrition [10]. Severe P deficiency markedly impaired both host plant growth and symbiotic N_2 fixation, and symbiotic N_2 fixation has a higher P requirement for optimal functioning than either host plant growth [11]. Poor nodulation of faba bean was reported in soils with low pH and P content [12]. Thus, P inputs are required for sustainable agricultural production in most acid soils of the tropics and subtropics.

Recently, more findings have emphasized the significant role of integrated soil fertility management involving combinations of microbial inoculants and inorganic and organic fertilizers in increasing the productivity and improving soil health and sustainability of environment in the long run [13]. The use of lime, acid tolerant varieties, application of compost, and manure were found to be effective in reducing soil acidity and Al toxicity in different areas [14].

Basically, lime should be applied to soils to create conditions conducive to the production of crops at the most favorable economic levels. To achieve such production on acid soils, it is necessary to apply sufficient lime to eliminate toxicities of Al and Mn, supply adequate levels of Ca and Mg, facilitate the utilization of water, create conditions which maximize the availability and uptake of the essential nutrients and the performance of the rhizobium-legume association, and create conditions which control soil pathogens [15]. Addition of manure and compost to acid soils is potentially a practicable low-input strategy for increasing soil pH, decreasing concentrations of Al, and reducing lime requirements [16]. Integrated application of farmyard manure (FYM) and lime have significantly and positively improved the yield of wheat [17].

Among the major factors attributed to low faba bean (*Vicia faba* L.) production is the declining of soil fertility, particularly soil acidity in the highlands of Ethiopia. Besides soil acidity and fertility decline, frequent disease occurrence, parasitic weeds, and lack of high yielding varieties limit the growth of faba bean. Consequently, the productivity of the crop revolves around $950 \text{ kg}\cdot\text{ha}^{-1}$ at Lay Gayint district which is below the national average of $1300 \text{ kg}\cdot\text{ha}^{-1}$ and the world average of $1700 \text{ kg}\cdot\text{ha}^{-1}$ [18].

The study area is characterized by a high amount of rainfall and undulating topography, which contribute to leaching of ions and surface soil erosion. As a result, the soils

of the cultivated lands are prone to soil acidity and poor fertility. Most farmers have the experience of adding compost and FYM to soils growing cereals, although with rates not well quantified. In addition, the crop management practices of the farmers do not fully address the nutrient requirement of legume crops such as faba bean. In many of the rural areas, the majority of the farmers presume that pulses need little or no amendments. The practice of liming is an emerging technology in the country to manage soils affected by acidity. However, the amount of lime required for various crops, its effect with combination of inorganic and organic fertilizers at different locations has not been sufficiently addressed.

Although faba bean is classified as N_2 -fixing legume plant, effective root growth and nodule formation is restricted in acid soils where the availability of the essential plant nutrients like P and Ca are deficient. Therefore, to maximize the growth of the crop and increase soil fertility, maintaining the optimum pH range of the soil and improving the soil nutrient content call for progressive research. Thus, the specific objective of this experiment was to investigate the effects of lime, mineral P, FYM, compost, and rhizobium on the growth, nodulation, and nutrient uptake of faba bean (*Vicia faba* L.) in cultivated acid soils under greenhouse conditions.

2. Materials and Methods

2.1. Description of the Study Area. The study area is located in the middle and lower parts of Guna mountain in Lay Gayint District, Northwestern Ethiopia, which lies between $11^{\circ}32'$ to $12^{\circ}03'N$ latitude and $37^{\circ}31'$ to $38^{\circ}43'E$ longitude (Figure 1). The rainfall pattern is unimodal, stretching from May to September. The annual rainfall varies from 600 to 1100 mm, which is erratically distributed. The average annual minimum, maximum, and mean temperatures are 9, 19, and $14^{\circ}C$, respectively. The land use pattern indicates 24% of the area is cultivated and planted with annual and perennial crops, while the area under grazing and browsing, forests and shrubs, settlements, and wastelands accounts for about 19%, 0.6%, 8%, and 17%, respectively. Agroecologically, about 40% of the district is classified as *Dega*, 45% is considered as *WoinaDega*, and *Wurich* and *Kola* cover 8 and 7%, respectively. The soil is clay in texture with bulk density of $1.3 \text{ g}\cdot\text{cm}^{-3}$. Chemically, the soil in the area is characterized with very strongly acidic in reaction and low available P. The exchangeable soil acidity was $4.04 \text{ cmol}_c\cdot\text{kg}^{-1}$ soil, while total nitrogen was 0.19% [19].

2.2. Soil Sampling for Incubation and Pot Experiment. Six cultivated lands were selected from Yikalo watershed. Eight surface soil subsamples (0–20 cm depth) were collected from each land using auger and bulked to make one composite soil sample for soil pH determination in the field. Based on field soil pH test, bulk soil samples from these fields were collected using spade for greenhouse incubation and pot experiment.

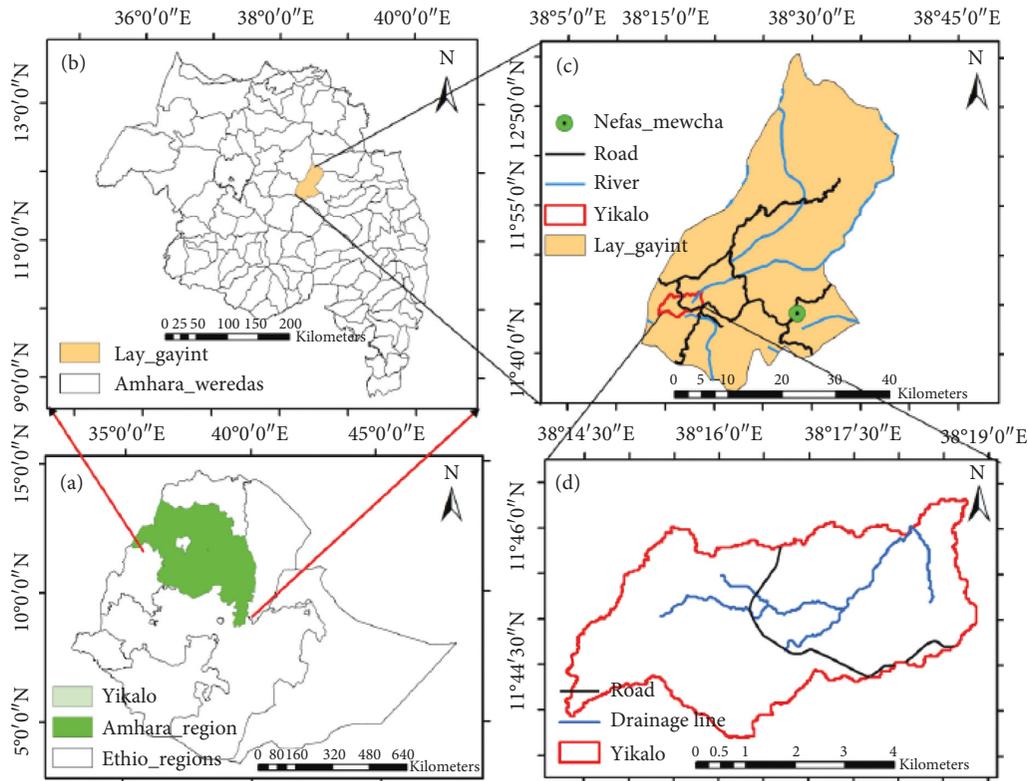


FIGURE 1: Location map of the study area. (a) Amhara National Regional State in Ethiopia (ANRS), (b) Lay Gayint district in ANRS, (c) study area, and (d) drainage lines.

2.3. Incubation Study. Based on pH and lime requirement (LR), composite soil samples of the acid soils were selected for this experiment. Air-dried soil samples were broken into aggregates, and filled in plastic pots having a capacity of 5 kg soil. Lime, mineral P as triple super phosphate (TSP) fertilizer, FYM, compost, and rhizobium were applied separately and in systematic combination at different rates. A completely randomized design (CRD) was used, and treatments were replicated three times. Farmyard manure and compost, dried and allowed to pass through a 0.25 mm sieve, were added. Farmyard manure was collected from Abaregay Dairy Farm in DebreTabor. Compost was prepared from wheat straw, manure, green leaves, and a thin layer of topsoil supplied with moisture and aeration conditions. The total C contents were 13.87 and 18.41% with a corresponding C:N ratio of 12.5 and 20.2 for FYM and compost, respectively, as analyzed by Fekadu et al. [19]. Lime was collected from Dejen cement factory in Ethiopia. Lime, which passed through 50 and 100 mesh size, was added based on the LR of the soil. The lime used for the experiment was found to have a CCE of 93.8%. Lime, FYM, and compost were incubated for 40 days prior to planting [19].

2.4. Pot Experiment. After 40 days of incubation of lime, FYM, and compost, mineral P was applied in the form of banding at planting. Seeds of faba bean (*Vicia faba* L.) were obtained from the Adet Agricultural Research Center (AARC). *Rhizobium leguminosarum* biovar. *viciae* strain EAL-110, which is a peat based commercial inoculant, was

used. It was accessed from the Menagesha Biotech Industry (MBI), commercial center in Addis Ababa, Ethiopia. The seeds were inoculated following the procedures as described by Fekadu et al. [19]. Five faba bean seeds were sown for each pot which were later reduced to three plants after emergence.

2.5. Nodulation Assessment. From each replication, the number nodule and its dry weight per plant were determined. The root of faba bean plant was washed by tap water. Nodules adhered to each plant root were also removed and separately spread on a sieve for some minutes until the water was drained from the surface of the nodule. Finally, the average number of nodules plant⁻¹ was recorded for each treatment. After the nodules were oven dried to 65°C for 48 hrs, the average nodule weight per plant was measured for each treatment as described by Delić et al. [20]. The cross sections of nodules and differences in the colour of nodular tissue were used for screening effective and ineffective nodules. The ineffective nodules were white to light green inside, while the effective nodules were characteristically pinkish brown [21].

2.6. Plant Growth Parameters, Tissue Sampling, and Analysis. Shoot length, number of branches and leaves, and shoot dry weight of faba bean plants were measured at 50% flowering. The plants were cut at ground level, and the youngest leaves (youngest fully emerged leaf and the apical growth of each plant) were collected and separated from the rest of the

plants for the analysis of N and P concentrations at 50% flowering from each treatment. The faba bean leaf samples were washed in sequence, first in detergent solution (0.2% liquid detergent), then, in dilute HCl (0.1 M HCl solution), and finally, in deionized water. The extra moisture was wiped out, and the samples were placed in new paper bags and dried to 70°C for 48 hrs.

Similarly, the total dry shoot biomass was determined after drying all the harvested above-ground plant parts of each pot at 70°C until a constant weight was achieved plus the dried weight of the youngest leaves. The dried leaves were ground in a stainless steel grinder, passed through a 0.5 mm sieve, and weighed. The N and P contents of the tissue samples were determined using the wet digestion method as described by Weldu and Habtegiel [22]. The method used for N analysis was made using the micro-Kjeldahl procedure [23], whereas the determination of P was carried out on the digest aliquot by Murphy and Riley [24]. The total N and P uptakes were calculated by multiplying the N and P contents in the tissue by the above ground dry shoot biomass of each treatment.

2.7. Postharvest Soil Analysis. After faba bean plants were harvested, soil samples from each pot were collected for the determination of N and P following the standard laboratory procedure where the micro-Kjeldahl method [23] was used to determine total N while Olsen et al. [25] was employed to determine available P.

2.8. Statistical Analysis. The data analyzed with the help of the generalized linear model (GLM) procedure of the statistical analysis system (SAS) software package version 9.1 [26]. The significant difference between treatments means was separated by using Duncan's Multiple Range Test (DMRT).

3. Results and Discussion

3.1. Effects of Treatments on Plant Height, Number of Branches, and Leaves. Plant height, number of branches, and leaves of faba bean were significantly ($P < 0.001$) affected by the treatments. The highest plant height (59.33 cm) was obtained in the pot that received 8 t FYM·ha⁻¹ + 30 kg P·ha⁻¹ + 5 t lime·ha⁻¹ + *Rhizobium* treatment followed by that of 8 t FYM·ha⁻¹ + 30 kg P·ha⁻¹ + 5 t lime·ha⁻¹ (Table 1). Sole application of 8 t FYM·ha⁻¹ increased plant height, number of branches, and leaves over the control, as compared with other sole treatment applications. Application of 8 t FYM·ha⁻¹ combined with 30 kg P·ha⁻¹ and 5 t lime·ha⁻¹ treated with or without rhizobium inoculation produced maximum number of branches and leaves plant⁻¹. As compared with application of compost in the treatment combinations (8 t compost·ha⁻¹ + 5 t lime·ha⁻¹, 8 t compost·ha⁻¹ + 30 kg P·ha⁻¹ + 5 t lime·ha⁻¹, and 4 t compost·ha⁻¹ + 15 kg P·ha⁻¹ + 10 t lime·ha⁻¹), application of FYM (8 t FYM·ha⁻¹ + 5 t lime·ha⁻¹, 8 t FYM·ha⁻¹ + 30 kg P·ha⁻¹ + 5 t lime·ha⁻¹, and 4 t FYM·ha⁻¹ + 15 kg P·ha⁻¹ + 10 t

lime·ha⁻¹) in the combinations significantly improved the growth parameters of faba bean.

On the other hand, at 30 kg P·ha⁻¹ application, increasing the lime rate from 5 to 10 t·ha⁻¹ without organic amendment did not bring significant response of plant height, number of branches, and leaves of faba bean. Another study on acid Nitisols of central Ethiopian highlands [27] reported significant increase of faba bean plant height and biomass due to combined application of 8 t FYM·ha⁻¹ with 39 kg P·ha⁻¹. Similarly, Tadele et al. [28] also indicated combined applications of FYM (4 and 8 t·ha⁻¹) with increasing rates of P from 0 to 60 kg·ha⁻¹ had positive influence on some of the growth and yield parameters of faba bean in southern Ethiopia.

The observed increase in the vegetative growth of faba bean due to 8 t·ha⁻¹ FYM in the treatment combination might be the supply of N and other nutrients in manure through mineralization. Besides, the increase in soil pH, the decrease in exchangeable Al³⁺, application of lime, and manure improved soil conditions for microorganism's development [29]. As the exchangeable Al³⁺ is reduced, the performance of plant roots are enhanced and nutrient uptake would be increased, and this would lead to increase in the plant growth parameters [30].

Considering sole application of treatments, FYM improved the growth of faba bean as compared with the others. This revealed the dual effect of FYM in ameliorating soil acidity and providing nutrients for promoting the growth of the crop. The difference observed in the growth of faba bean treated either with FYM or compost separately or with other amendments was attributed to the higher N and P contents in the FYM as compared with compost.

3.2. Shoot Dry Weight. Combined applications of organic and inorganic treatments significantly ($P < 0.001$) affected the shoot dry weight of faba bean. Addition of 8 t FYM·ha⁻¹ and 30 kg P·ha⁻¹ combined with 5 t lime·ha⁻¹ increased the shoot dry weight of faba bean (Table 1). In the same way, 4 t compost·ha⁻¹ combined with 15 kg P·ha⁻¹ and 10 t·ha⁻¹ lime resulted in significant shoot dry weight of faba bean. Rhizobium inoculation of seeds treated with 30 kg P·ha⁻¹ and 10 t lime·ha⁻¹ had the same significant effect of shoot dry weight as the soils received 15 kg P·ha⁻¹ and 4 t FYM·ha⁻¹ in combination with 5 t lime·ha⁻¹. Among sole treatments applied, FYM was better to increase shoot dry weight, though no statistically significant difference was observed with others.

The effect of full application of FYM with half rate of lime in improving shoot dry weight was equivalently significant with half rate of FYM or compost with full rate of lime. This is ascribed to the liming effect of FYM in raising soil pH, activating microorganisms, and releasing ions [3]. Chinthapalli et al. [31] compared organic and inorganic fertilizers, and the result indicated that the application of cow dung at 15 t·ha⁻¹ showed significant growth over the inorganic fertilizer urea and potassium chloride in terms of germination percentage, fresh weight and dry weight, plant height, shoot length, and root length as well as number of

TABLE 1: Effects of organic and inorganic amendments on the growth of faba bean.

Treatments	Plant height	Number of branches plant ⁻¹	Number of leaves plant ⁻¹	Shoot dry weight (g·plant ⁻¹)
Control	30.67j	6.22g	11.33j	2.74f
8 t compost·ha ⁻¹	37.33gh	6.33g	11.66j	2.87f
8 t FYM·ha ⁻¹	41.33gh	11.22bc	23.22def	3.68b-f
30 kg P·ha ⁻¹	33.67ij	7.78fg	16.22hi	3.40c-f
10 t lime·ha ⁻¹	41.67fgh	8.00fg	15.78ij	3.05def
30 kg P·ha ⁻¹ + 10 t lime·ha ⁻¹	47.33ef	10.11cde	20.78efg	3.90a-f
8 t compost·ha ⁻¹ + 5 t lime·ha ⁻¹	41.33gh	8.89def	19.22fgh	4.17a-e
8 t FYM·ha ⁻¹ + 5 t lime·ha ⁻¹	48.33de	9.22def	16.89ghi	3.91a-f
30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	42.33fg	9.11def	20.33efg	4.47abc
8 t compost·ha ⁻¹ + 30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	48.33de	10.33cd	25.33bcd	4.36abc
8 t FYM·ha ⁻¹ + 30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	58.67a	13.78a	37.11a	5.14a
4 t compost·ha ⁻¹ + 15 kg P·ha ⁻¹ + 10 t lime·ha ⁻¹	50.00cde	10.78bcd	25.56bcd	4.87ab
4 t FYM·ha ⁻¹ + 15 kg P·ha ⁻¹ + 10 t lime·ha ⁻¹	57.00ab	12.33ab	29.56b	4.61abc
4 t compost·ha ⁻¹ + 15 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	53.58a-d	9.29def	25.48bcd	4.55abc
4 t FYM·ha ⁻¹ + 15 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	55.67abc	10.89bcd	28.30bc	4.15a-e
30 kg P·ha ⁻¹ + 10 t·ha ⁻¹ lime + <i>Rhizobium</i>	55.67abc	11.33bc	24.78cde	4.83ab
8 t·ha ⁻¹ compost + 30 kg·ha ⁻¹ P + 5 t lime·ha ⁻¹ + <i>Rhizobium</i>	51.33b-e	12.44ab	28.44bc	4.19a-e
8 t·ha ⁻¹ FYM + 30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹ + <i>Rhizobium</i>	59.33a	14.00a	38.67a	4.28a-d
4 t FYM·ha ⁻¹ + 15 kg·ha ⁻¹ P + 5 t lime·ha ⁻¹ + <i>Rhizobium</i>	53.67a-d	10.00cde	23.22def	4.82ab
<i>Rhizobium</i> only	35.67hij	8.22ef	16.44hhi	3.11def
CV (%)	6.80	10.34	12.21	16.99

Means within a column followed by the same letter are not significantly different at $P \geq 0.001$; CV = coefficient of variation.

leaves of faba bean and pea. The increased biomass of the plant could be partially attributed to the nutrient released during decomposition of FYM.

3.3. Nodule Number and Nodule Dry Weight. Total nodule number, effective nodule number, and nodule dry weight per plant were significantly ($P < 0.001$) affected by combined application of treatments (Table 2). Farmyard manure was superior to compost; however, their combined application of FYM with P and lime was far superior to the individual ones. Application of 4 t FYM·ha⁻¹ and 15 kg P·ha⁻¹ combined with 10 t lime·ha⁻¹ showed significant increases in nodule number and nodule dry weight. The same effect was observed in soils treated with 30 kg·ha⁻¹ P with 10 t lime·ha⁻¹ and rhizobium inoculation. This indicated that unlike the above ground growth parameter, which increased with increasing FYM from 4 to 8 t·ha⁻¹, nodulation was reduced with increasing rate of FYM in the treatment combinations. Sole treatment of lime improved nodulation as compared with either sole treatment of compost, FYM, or rhizobium. This could be due to favorable conditions like pH created for stimulating the activity of resident faba bean nodulating bacteria.

Rhizobium inoculation alone did not bring significant change in nodulation of faba bean under acid soil condition. Nodulation was significantly improved after the soil acidity was reclaimed with lime, and where there was P in the treatment combination. Application of FYM leads to increase in nodules production, nodule dry weight, dry matter production, and seed yields of soybeans, but the production

of nodules fall sharply at application rates higher than 8 t of FYM [32]. This effect was attributed to the increase in available C content of the soil that created favorable media for rhizobium, and the role of FYM in reducing soil acidity and increasing P availability. The effect of FYM in improving nodulation might also be due to the presence of other vital nutrients in FYM essential for both the host plant and microsymbiont [33]. Besides, different forms of N compounds, such as NO_3^- and NH_4^+ in FYM might be released upon decomposition, which the plants take up readily until the nodules are well established. Singh [34] reviewed that addition of 10 to 15 t FYM·ha⁻¹ stimulated the growth and activity of microorganisms and therefore increased the number and dry weight of nodules in soyabean. Increased number of nodules per plant due to manure application was observed in lablab, common bean, and green gram [35]. This might be related to the supply of substrate for the growth of microorganisms and maintain in a favorable nutritional balance and soil physical properties. Negi et al. [36] compared FYM, NPK, and lime on pea and concluded that significant increase in nodule number was achieved due to FYM. These authors also suggested liming further increased the nodule number by 401.87 and 433.85% at 110 and 140 days after sowing, respectively. Integrated use of different P sources and rhizobium also increased number of nodules per plant, nodule fresh weight, and nodule dry weight [37]. Phosphorus is believed to initiate nodule formation and enhance the number of nodule primordial and is essential for the development and functioning of formed nodules [38]. The improvement of nodulation as a result of lime could be due to the reduction of acidity that enhanced

TABLE 2: Effects of organic and inorganic amendments on the nodulation of faba bean.

Treatments	Nodule number plant ⁻¹	Effective nodule number plant ⁻¹	Nodule dry weight (mg·plant ⁻¹)
Control	33.00j	11.00g	20.00i
8 t compost·ha ⁻¹	53.67hi	17.00fg	37.67h
8 t FYM·ha ⁻¹	60.00h	23.33efg	42.67h
30 kg P·ha ⁻¹	33.33j	10.33g	31.00hi
10 t lime·ha ⁻¹	85.00fg	29.00def	67.67fg
30 kg P·ha ⁻¹ + 10 t lime·ha ⁻¹	125.67b	43bcd	97.33cd
8 t compost·ha ⁻¹ + 5 t lime·ha ⁻¹	59.67h	16.67fg	41.00h
8 t FYM·ha ⁻¹ + 5 t lime·ha ⁻¹	104.67cde	34b-e	85.67de
30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	75.00g	20.33efg	56.00g
8 t compost·ha ⁻¹ + 30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	99.67de	30.00c-f	78.00ef
8 t FYM·ha ⁻¹ + 30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	116.67bc	50.00ab	92.00de
4 t compost·ha ⁻¹ + 15 kg P·ha ⁻¹ + 10 t lime·ha ⁻¹	112.67bcd	39.67bcd	91.67de
4 t FYM·ha ⁻¹ + 15 kg P·ha ⁻¹ + 10 t lime·ha ⁻¹	153.33a	59.33a	131.33a
4 t compost·ha ⁻¹ + 15 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	74.50g	30.67c-f	55.25g
4 t FYM·ha ⁻¹ + 15 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	95.67ef	30.67c-f	79.00ef
30 kg P·ha ⁻¹ + 10 t lime·ha ⁻¹ + <i>Rhizobium</i>	147.00a	49.00ab	111.67b
8 t·ha ⁻¹ compost + 30 kg·ha ⁻¹ P + 5 t lime·ha ⁻¹ + <i>Rhizobium</i>	126.33b	46.00abc	107.00bc
8 t·ha ⁻¹ FYM + 30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹ + <i>Rhizobium</i>	122.33b	49.33ab	96.33 cd
15 kg·ha ⁻¹ P + 4 t FYM·ha ⁻¹ + 5 t lime·ha ⁻¹ + <i>Rhizobium</i>	107.67cde	40.67bcd	84.33ed
<i>Rhizobium</i> only	43.667ij	12.00g	29.00hi
CV (%)	8.25	26.47	10.47

Means within a column followed by the same letter are not significantly different at $P \geq 0.001$; CV = coefficient of variation.

bacteria proliferation and increased bioavailability of Ca, P, and Mo. Liming increases the Ca levels in the soil, which in turn enhances the root penetration into the deeper layers and also induced the normal distribution of nodules.

3.4. Tissue N and P Contents and Uptakes. Integrated application of organic and inorganic amendments significantly ($P < 0.001$) affected the N and P contents in the tissue of faba bean. Application of 8 t FYM·ha⁻¹ + 30 kg P·ha⁻¹ + 5 t lime·ha⁻¹ with inoculation of rhizobium demonstrated highest tissue N content (3.86%). The same treatment combination without inoculation also showed significant N content (3.83%) and N uptake followed by 4 t FYM·ha⁻¹ + 15 kg P·ha⁻¹ + 10 t·ha⁻¹ lime (Table 3). Significantly improved N content and uptake was observed due to integrated application of treatments over sole treatments and the control. Plants that received full dose of FYM and P with half rate of lime with inoculation showed N accumulation of 71% increase, but the same treatment without inoculation increased tissue N by 69% over the control.

This indicates that there was no improvement in N accumulation in the tissue of faba bean plants due to inoculation of rhizobium. Pronounced effect to N uptake was observed as a result of reducing soil acidity by application of lime and FYM.

Similarly, in an experiment conducted on common bean, high N level was obtained in the biomass of FYM-fertilized plants [39]. The highest N content obtained in the tissue is in the range of optimum N content (3.8 to 5.0%) of legume crops

[40] indicating that combined application of FYM, P, and lime could improve the growth and N uptake of faba bean. Increasing the level of P significantly increased the N uptake by the plant that could be attributed to the complementary role played by P in the N removal by the faba bean [41].

Significant ($P < 0.001$) tissue P content and uptake was obtained with combined application of organic and inorganic treatments (Table 3). Application of 8 t FYM ha⁻¹ + 30 kg P·ha⁻¹ + 5 t·ha⁻¹ lime resulted in the highest P content (0.219%) in the tissue of faba bean. As compared to the control, 92% increase in P content was observed due to full rates of FYM and P with half rate of lime. Including compost with lime and P also improved significantly P uptake compared to the P or lime treatments applied separately or in the combination of lime and P. For example, addition of 8 t compost·ha⁻¹ + 30 kg P·ha⁻¹ + 5 t lime·ha⁻¹ + *Rhizobium* improved P content by 70% over the control.

The increased P content could be due to the improvement of nodules and N utilization and better vegetative growth as a result of the applied manure. Including P in the treatment combination might increase the physiological activity of the roots and consequently increase P concentration and uptake by faba bean plant. The decomposition of OM and the resultant availability of nutrients in the soil could also increase uptake by the roots of the plant. Furthermore, faba bean being N₂ fixing crop might absorb high amount of P for energy expense. Consistent with this finding, El-kotb [42] revealed that N, P, and K uptake by grain and straw were increased significantly by FYM and compost applications. This trend of higher uptake of N and P

TABLE 3: Effects of organic and inorganic amendments on tissue N and P concentrations and uptakes and postharvest soil N and P.

Treatments	Tissue N content (%)	N uptake (kg·ha ⁻¹)	Tissue P content (%)	P uptake (kg·ha ⁻¹)	Soil N after harvest (%)	Soil P after harvest (mg·kg ⁻¹)	Soil pH after harvest
Control	2.26f	45.35h	0.114k	2.28g	0.18g	4.27l	4.95lm
8 t compost·ha ⁻¹	2.47f	47.67h	0.124jk	2.38g	0.22d	5.38j	5.36kl
8 t FYM·ha ⁻¹	2.80e	72.32fgh	0.130j	3.36fg	0.22d	6.09h	5.35klm
30 kg P·ha ⁻¹	2.43f	57.74gh	0.155i	3.71efg	0.19fg	4.98k	4.89klm
10 t lime·ha ⁻¹	2.84e	60.47gh	0.169ghi	3.63efg	0.19fg	6.35efg	6.11c-g
30 kg P·ha ⁻¹ + 10 t lime·ha ⁻¹	2.90e	78.73efg	0.182d-g	4.99cde	0.23cd	6.37ef	6.10c-g
8 t compost·ha ⁻¹ + 5 t lime·ha ⁻¹	3.08ed	93.42c-e	0.165hi	4.79def	0.19fg	5.78i	5.93e-i
8 t FYM·ha ⁻¹ + 5 t lime·ha ⁻¹	3.45bc	94.53c-f	0.1707f-i	4.67def	0.23cd	6.76d	5.56jk
30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	2.88e	90.31def	0.173e-h	5.41bcd	0.19fg	6.12fgh	5.89f-i
8 t compost·ha ⁻¹ + 30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	3.49bc	106.38bcd	0.185c-f	5.66a-d	0.21def	6.41e	5.87g-j
8 t FYM·ha ⁻¹ + 30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	3.83a	137.81a	0.219a	7.13a	0.28a	7.61a	5.79hij
4 t compost·ha ⁻¹ + 15 kg P·ha ⁻¹ + 10 t lime·ha ⁻¹	3.32cd	113.36a-d	0.191bcd	6.52abc	0.23cd	6.16e-h	6.03c-h
4 t FYM·ha ⁻¹ + 15 kg P·ha ⁻¹ + 10 t lime·ha ⁻¹	3.75ab	108.93bcd	0.193bcd	6.85ab	0.26ab	7.00cd	6.19b-f
4 t compost·ha ⁻¹ + 15 kg P·ha ⁻¹ + 5 t lime ha ⁻¹	3.32cd	77.16efg	0.184c-f	4.28	0.21de	6.35efg	5.86g-j
4 t FYM·ha ⁻¹ + 15 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹	3.44c	100.28b-e	0.192bcd	5.61a-d	0.22d	6.96cd	5.75hij
30 kg P·ha ⁻¹ + 10 t lime·ha ⁻¹ + Rhizobium	3.49bc	118.06abc	0.187b-e	6.34abc	0.21de	6.12gh	nd
8 t·ha ⁻¹ compost + 30 kg·ha ⁻¹ P + 5 t lime·ha ⁻¹ + Rhizobium	3.49bc	102.53b-e	0.194bcd	5.70a-d	0.22d	7.02c	nd
8 t·ha ⁻¹ FYM + 30 kg P·ha ⁻¹ + 5 t lime·ha ⁻¹ + Rhizobium	3.86a	126.56ab	0.203b	6.93ab	0.27ab	7.29b	nd
4 t FYM·ha ⁻¹ + 15 kg·ha ⁻¹ P + 5 t lime·ha ⁻¹ + Rhizobium	3.37c	115.82a-d	0.199bc	6.01a-d	0.25bc	6.32e-h	nd
Rhizobium only	2.44f	53.11gh	0.113k	2.46g	0.19fg	4.26l	nd
CV (%)	5.78	18.28	5.52	18.79	5.84	2.43	3.32

Means within a column followed by the same letter are not significantly different at $P \geq 0.001$; CV = coefficient of variation; nd = not determined.

and in the treatments received FYM could be due to the increased N and P availability in soil and the direct uptake of N and P by leaves resulting in higher production of chlorophyll, dry mater, and higher uptake of macronutrients by the crop [43]. The increased availability of P due to application of FYM or compost could be the result of gradual decomposition of OM and the release of organic acids that bound with Al and decreased P fixation in acid soil [44].

Plant uptake of P is enhanced with liming acid soils; an effect often referred to as “P spring effect” of lime [45]. These authors explained that liming could increase plant P uptake by decreasing Al, rather than by increasing P availability alone in soils high in exchangeable acidity. This also improves root growth which alleviates Al toxicity by allowing a greater volume of soil to be explored [46]. Ca²⁺ in lime displaces Al³⁺, Fe²⁺, and H⁺ ions from the soil sorption sites which causes reduction in soil acidity and P fixation thereby increasing P availability; this was reflected in increased shoot P, N, biomass and nodulation [47].

3.5. Postharvest Soil N and P. The analysis of soil N after the removal of the crop showed that application of full rate of FYM and P with half rate of lime and rhizobium inoculation

gave significantly ($P < 0.001$) the highest value followed by half rate of FYM and P with full rate of lime (Table 3). Among sole treatments applied, significant postharvest N was obtained in the soil due to application of 8 t FYM·ha⁻¹ or 8 t compost·ha⁻¹, over the control (Table 3). Though the crop is N fixer, the amount of N recorded in the control and rhizobium only plots was low indicating that soil acidity, if not managed, could deprive atmospheric N₂ fixation. The higher N content observed in the combined treatments could be due to the effects of amendments in increasing soil pH; supplying food and energy to activate the microorganisms to decompose the added OM.

Liming and rhizobium inoculation play significant contribution in N fixation thereby improving soil N [35]. The role of P in increasing soil N could be related with improved nodulation and N₂ fixation. In the same way, Hellal et al. [43] reported amending soils with FYM increased soil N.

Postharvest soil P analysis indicated that application of 8 t FYM·ha⁻¹ + 30 kg P·ha⁻¹ + 5 t lime·ha⁻¹ increased soil P significantly ($P < 0.001$) followed by the same treatment combination plus rhizobium inoculation. Comparing sole treatment applications, addition of 10 t lime·ha⁻¹ showed significant postharvest soil P as compared to the control. The

increased soil P obtained due to combined application of FYM, P, and lime could be due to the integrated effect of the treatments in reducing soil acidity and exchangeable Al^{3+} and increasing P availability [3]. Many studies have indicated that addition of organic residues to acid soils can reduce Al toxicity (hence lowering the lime requirement) and enhance P availability [3]. Increasing lime rates increased soil pH and exchangeable bases thereby reducing the magnitude of soil acidity, exchangeable acidity, and Al saturation and increased availability of P [2, 3].

4. Conclusion

This finding has shown that sole or combined application of organic and inorganic amendments contributed significantly in improving the growth characteristics and nodulation and nutrient uptake of faba bean. More specifically, significant increment in shoot length, number of leaves and branches, and shoot dry weight were obtained with 8 t FYM·ha⁻¹ + 30 kg P·ha⁻¹ + 5 t lime·ha⁻¹ with or without rhizobium inoculation. Likewise, improved nutrient contents in the tissue and uptakes were observed with these treatment combinations. Increased nodule number and dry weight of faba bean were recorded due to application of 4 t FYM·ha⁻¹ + 15 kg P·ha⁻¹ + 10 t lime·ha⁻¹ followed by 30 kg P·ha⁻¹ + 10 t lime·ha⁻¹ + Rhizobium. Significant amount of N and P were accumulated in the soil after removal of the crop with the addition of 8 t FYM·ha⁻¹ + 30 kg P·ha⁻¹ + 5 t lime·ha⁻¹. The results indicated that combined use of lime, FYM, and P fertilizers could improve the growth characteristics, nodulation, and nutrient uptakes of faba bean in acid soil of the study site. However, the contribution of rhizobium inoculation was not effective. This shows that improving soil pH and reducing exchangeable acidity and Al^{3+} through application of organic and inorganic amendments could stimulate the existing soil rhizobium to improve the nodulation and the growth of faba bean.

Therefore, the finding could allow the farmers to utilize the locally available resources such as manure and compost integrated with commercially purchased inputs like TSP and lime to grow faba bean in acid soils. In addition to savings, the soil fertility could be improved and acidity will be reduced. However, various strains of rhizobium in combination with amendments should be tested on the crop under such kind of acid soil conditions. In order to come up with comprehensive recommendation, the effects of amendments used in this study should be tested under field condition.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

Endalkachew Fekadu is an employed staff of Woldia University.

Conflicts of Interest

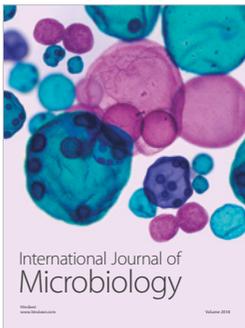
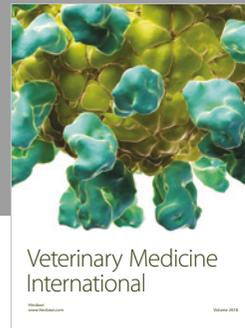
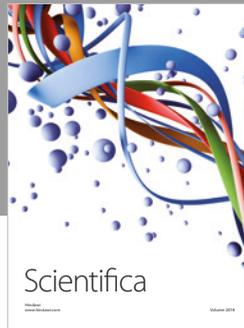
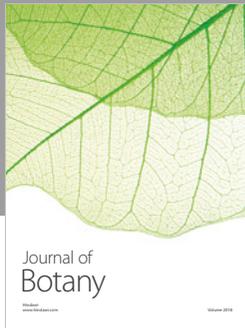
The authors declare that there are no conflicts of interest regarding the publication of this paper.

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