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Research Article

Yield Response of Faba Bean to Lime, NPSB, and Rhizobium Inoculation in Kiremu District, Western Ethiopia

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Faba bean (*Vicia faba* L.) is one of the most important winter legume crops for human consumption as a green or dried, fresh, or canned. Low soil fertility and acidity are the major constraints of faba bean production in Ethiopia. A field experiment was conducted in the Kiremu district of West Oromia, Ethiopia, under rain-fed conditions on a farmer's field to evaluate the effect of different rates of lime and NPSB-blended fertilizer application with and without inoculation on yield components and yield of faba bean. The three factors, lime rates (0, 2, and 4 $t\,ha^{-1}$), mineral fertilizer rates (0, 60, 120, and 180 $kg{\cdot}ha^{-1}$ NPSB), and rhizobium inoculation (with and without), were combined in 3 x 4 x 2 factorial arrangement of RCBD in three replications. The data were collected on yield and yield components and subjected to the analysis of variance (ANOVA). The ANOVA results revealed that the number of pods per plant, number of seeds per pod, hundred seeds weight, harvest index, aboveground biomass, and grain yield were significantly affected by the treatment. Therefore, the highest faba bean yield was obtained from the application of 2 *t* limes ha^{-1}, 120 NPSB ha^{-1}, and 500 $g{\cdot}ha^{-1}$ rhizobium inoculation, and thus, the integrated application of the aforementioned rates of lime, NPSB, and rhizobium inoculation could be recommended for maximizing the productivity profitability of faba bean production in the study area and similar agro-ecologies.

1. Introduction

Faba bean (*Vicia faba* L.) is one of the earliest domesticated food legumes in the world [1], which is grown under rain-fed as well as irrigated conditions in many parts of the world. It is among the most important grain legume crops grown in Ethiopia for food as a source of protein and for enriching the soils with nitrogen as a rotation crop ameliorating soil fertility. It has a high nutritional value and is used almost daily in the human diet of many Ethiopians [2]. Seeds of leguminous plants are a valuable source of amino acids, especially lysine, in human and animal diets [3]. Ethiopia's major faba bean crop-producing regions are Oromia, Amhara, Benishangul-Gumuz, and highland parts of Tigray [4]. Despite the importance of the crop in the traditional farming systems, its production and productivity have been declining in the last decades due to poor soil fertility and inadequate plant nutrition, soil acidity, and the replacement of traditional cropping systems with cereal-based systems among other factors [5].

Varieties of faba bean released in specific National Agricultural Research Centers require demonstration with appropriate crop management practices including nutrient management to exploit its production potential. Nitrogen (N) is a nutrient required by the crop in comparatively larger amounts than the other elements. The application of commercial fertilizers as a way of correcting N deficiency for the enhancement of the productivity of crops becomes important [6]. Although faba bean can fix atmospheric N_2, fixation is very low to meet the N demand of the crop due to poor nodulation resulting from soil acidity and deficiency of starter N in the soils [7]. Furthermore, atmospheric N_2 fixation by legumes is very sensitive to phosphorous (P) deficiency because P deficiency reduces nodule mass [8]. It has been suggested that the high energy costs of supporting the rhizobia symbiosis require an uptake of a large amount of P to meet the need for adenosine triphosphate [9]. Inoculation of faba bean with local rhizobia isolates at planting time is recommended to improve N fixation and enhance legume productivity [10,11]. On the other hand, soil acidity has become a serious threat to crop production in most high lands of Ethiopia in general and in the western part of the country in particular. Currently, it is estimated that about 40% of the total arable land in Ethiopia is affected by soil acidity [12,13]. The ideal soil pH for growing faba bean is ≥ 7. In soils with pH lower than 5, survival of rhizobium becomes critical [14]. Therefore, liming is required for faba bean cultivation when the soil pH level is below 6 [15]. Different studies on liming showed a linear effect up to 3.6 $t{\cdot}ha^{-1}$, and the increase in pH was 0.2 pH units per ton of lime [16, 17]. As NPSB affects the nodulation and N fixation, while the application of effective rhizobium can reduce chemical N fertilizer consumption, the information on the rates of NPSB fertilizers that best maximize nodulation needs to be identified for the development of integrated nutrient management in faba bean production [18–20].

Although faba bean is one of the most important food legumes cultivated in Ethiopia as well as in the study area, its productivity remained very poor (2.16 $t{\cdot}ha^{-1}$) compared to the yield potential of 5 $t{\cdot}ha^{-1}$ [21]. Low soil fertility and soil acidity are the major detrimental factors that contribute to the poor productivity and production of faba bean in the study area. Additionally, farmers are not even having an idea about using lime to reduce the acidity of the soil, and also they are even not familiarized to use NPSB chemical fertilizer, improved variety, and biofertilizers to improve faba bean production [22]. Thus, this experiment was designed to evaluate the combined effects of lime and mineral NPSB-blended fertilizer application with and without rhizobium inoculation on the yield and yield components of faba bean.

2. Materials and Methods

2.1. Description of the Study Area. The experiment was conducted in the Kiremu district, West Oromia regional state, of Ethiopia on farmer's field during the main season of 2019–2020. The experimental site is located at 09^0N $34'26'$ E longitude and latitude 56.7^0N 37.1^0 E (Figure 1). The elevation of the district ranged from 1500 to 2200 m.a.s.l with the maximum and minimum average temperatures of 27 and 13^0C, respectively. The total annual rainfall is ranged from 770 to 1760 mm (Figure 2). The preplanting physical and chemical properties of the soil of the experimental site are described in Table 1.

2.2. Soil Sample Collection and Analysis. Before planting, one composite soil sample was taken from the field at depth of 0–20 cm. The samples were air-dried, ground using a pestle and a mortar, and allowed to pass through a 2-mm sieve. The sample was analyzed for organic matter, total N, soil pH, available *P*, cation exchange capacity (CEC), and textural analysis using standard procedures in the Nekemte soil laboratory. The organic matter content was determined by the volumetric method [23]. Total nitrogen was analyzed by the micro-Kjeldahl digestion method [24]; the CEC was measured after saturating the soil with 1N ammonium acetate (NH_4OAc) and displacing it with 1N NaOAc [25]; available P was be determined by Olsen's method [26]; the soil pH was measured in water, at soil:water ratio, 1 : 2.5, using a combined glass electrode by a digital pH meter [27]. Soil texture was determined using the Bouyoucos hydrometer method [28].

2.3. Experimental Materials. The faba bean variety Hachalu, which was developed and released by Holota Agricultural Research Center in 2002, was used for the experiment. The variety is high yielding (2400–3500 $kg\,ha^{-1}$) and adaptable over a wide range of altitudes (1900–2800 m.a.s.l.). Rhizobium strain TAL_1035 was also kindly obtained from the Biofertilizers Production Unit, Holota Agricultural Research Center, EIAR, Ethiopia. Rhizobial strain (rhizobium TAL_1035), originally collected by Holota Agricultural Research Center in Ethiopia, was previously characterized as a superior isolate in nodule formation, nitrogen fixation, and uptake, as well as shoot biomass production of faba bean [29]. The NPSB-blended fertilizer (18.9% N, 37.7% P, 6.95% S, and 0.1% B) and lime ($CaCO_3$) were used in the experiment.

2.4. Treatments and Experimental Design. The treatment consisted of four levels of NPSB fertilizer (0, 60, 120, and 180 $kg\,ha^{-1}$), three levels of lime (0, 2, and 4 $t{\cdot}ha^{-1}$), and two levels of rhizobium strain TAL_1035 (with 500g ha^{-1} and without). The complete treatment combination is presented in Table 2. The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement with three replications. Rhizobium strain was formulated as 10 g of sugar dilute with 100 ml of water, and one packet of inoculums (125 g) was mixed with 200 ml of water. The seeds were mixed with the inoculum to have a uniform coating dried under shade for 30 minutes. The size of each experimental plot was 3 m × 2.4 m, and the seed is planted with an intra- and interplant spacing of 10 cm and 40 cm, respectively, maintaining a distance of 0.5 m and 1 m between adjacent plots and blocks, respectively. Lime was applied a month before sowing the faba bean, while NPSB fertilizer was applied in the band near the crop row and incorporated into the soils at sowing time. The rhizobium strain was inoculated to the seeds before sowing. The crop planning was undertaken in early June and harvested in October 2019.

2.5. Data Collected

2.5.1. Growth Parameter

(1) Leaf area (cm^2): five plants were randomly taken from each plot and the leaf area was recorded at the peak growth stage of the plant. The leaf area was obtained according to Peksen [30]. That is,

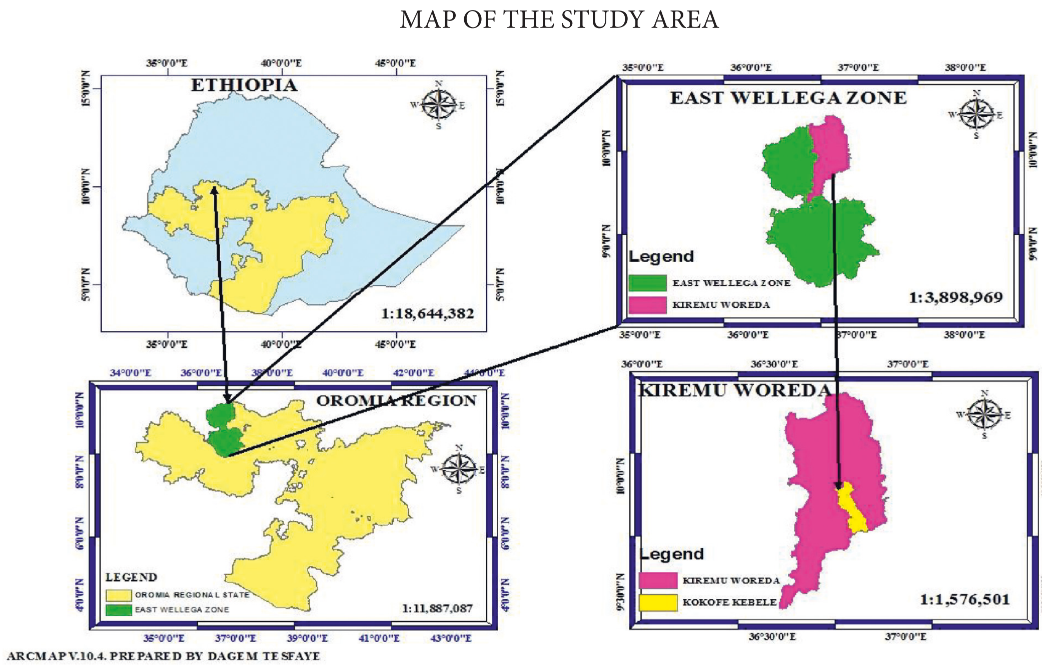

Figure 1: Map of the study area. Source: National Meteorology (2019), Source: (Kiremu District Profile, 2019).

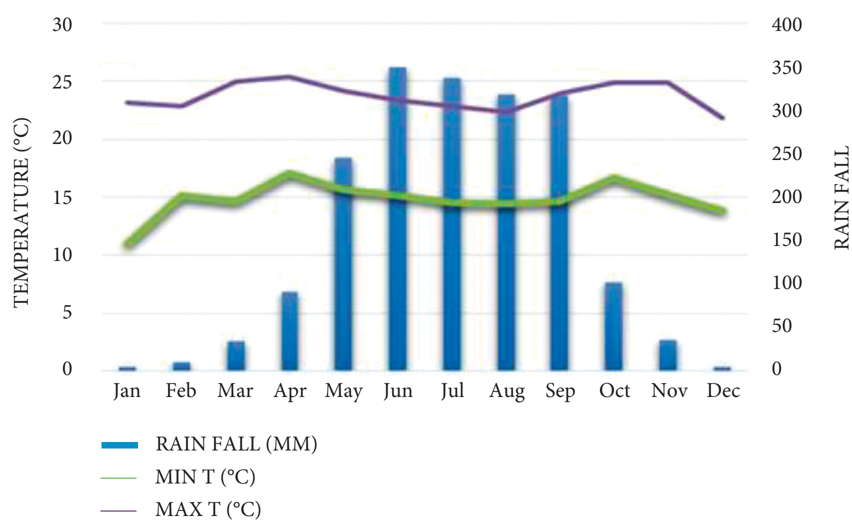

Figure 2: The monthly average rainfall, and maximum and minimum temperatures from 2004 to 2016 in the study area.

Table 1: Physical and chemical properties of soil experimental site before planting faba beans.

Soil properties	Values	Rating
Chemical properties		
PH	4.55	Very strongly acidic
Organic carbon%	0.342	Very low
Total nitrogen%	0.029	Low
Available phosphorus (ppm)	4.56	Low
CEC (cmol (+)/kg)	14.7	Medium
Physical properties		
Soil textural class	Clay 26%, sand 50%, and silt 24%	Sandy clay loam

0.919 + 0.682 x L *x* W, where *L* is the length of the leaf, W is the width of the leaf, and 0.919 + 0.682 is the coefficient of the faba bean leaf as a correction factor.

(2) Plant height (cm): it was measured at physiological maturity from the base of the plant to the tip (terminal bud of the plant). It was done randomly taking five plants per plot from the net plot. The graduated stick was used for measuring the height, from the ground level to the terminal bud of the main stem, and the mean of the five plants will be determined.

(3) Effective nodules: ten nodules were randomly taken from each of the five sample plants per plot and carefully sliced to visually differentiate effective nodules. The effective nodules were separated by their pink color. The nodules with

pink coloration were counted and converted to a percentage by dividing the number of pink-colored nodules per plant by the total number of nodules per plant multiplied by 100 according to Sara et al. [31].

2.5.2. Yield Data

(1) Aboveground dry biomass: at physiological maturity, five plants were randomly selected from the sampling row and dried under the sun to constant weight to determine the aboveground dry biomass. The total biomass yield was determined by multiplying the dry biomass per plant by the total number of plants in the net plot area and then converted into kg ha^{-1}.

(2) Grain yield (kg ha-1): the total weight of the air-dried seeds harvested from each net plot (adjusted to 10% moisture level) was recorded separately in kilograms using sensitive balance, and total yield ha^{-1} was computed.

2.5.3. Yield Component Data

(1) Harvest index (HI): the HI (%) was calculated as the ratio of grain yield ha^{-1} to the total aboveground dry biomass yield ha^{-1} multiplied by 100.

(2) Hundred (100) seed weight (g): the weight of 100 seeds was determined by carefully counting 100 seeds from the total harvest per net plot area and weighing the seed using a sensitive balance.

(3) Seed number per pod: ten pods were randomly taken from the harvest per plot. The seeds inside each pod were counted and averaged over the number of pods taken per plot.

(4) Pod per plant: five plants per plot were randomly taken at harvest and fertile mature pods were counted and averaged over the five plants to obtain pods per plant.

2.6. Statistical Data Analysis. Data were subjected to the analysis of (ANOVA) variance using RCBD in the factorial arrangement experiment and the SAS version 9.1.3 software [32]. Replications were reckoned as random effects in the statistical model. Treatments exhibited significant differences and separated. The means were compared using the Duncan multiple range test (DMRT) at a 5% level of significance.

2.7. Economic Analysis. An economic analysis was performed using the partial budget procedure described by CIMMYT [33]. The marginal rate of return was calculated by dividing the change in a net increase in the yield of faba bean due to the application of each NPSB and rhizobium inoculation by the cost of NPSB and rhizobium inoculants applied. Labor cost involved for the inoculation of faba bean seeds with rhizobium and application of NPSB fertilizer was recorded and used for this analysis. The price of the faba bean grain was valued at an average open market price (ETB kg^{-1}) at the time of harvest. The net returns and other economic analysis were based on the formula developed by CIMMYT [33].

3. Result and Discussion

3.1. Growth and Nodulation

3.1.1. Leaf Area (cm^2). The ANOVA showed that the main factors and the interaction effect of lime with either rhizobium inoculation or NPSB rate were significant ($p < 0.05$) on the leaf area of the faba bean. The highest leaf area was observed from the combination of rhizobium inoculation with 4 *t* lime ha^{-1}, and this is statistically similar to the leaf area obtained at the application of a combination of rhizobium inoculation with 2 *t* lime ha^{-1}. In contrast, the lowest leaf area was recorded without lime, and inoculation of rhizobium, which is at par with treatment, received no lime but rhizobium-inoculated (Table 3).

Regarding the interaction effect of lime with the NPSB rate, the highest leaf area obtained from the combination of 180 kg NPSB ha^{-1} with 2 *t* lime ha^{-1}, which is statistically similar to the leaf area obtained from the combination of 120 kg NPSB ha^{-1} with 2 *t* lime ha^{-1} and 120 kg NPSB ha^{-1} with 4 *t* lime ha^{-1}. In contrast, the lowest leaf area was obtained from treatment supplied with no lime and fertilizer (Table 3).

This might be since an adequate supply of N, P, S, and B could have increased the number of branches per plant and leaf area, which in turn increases the photosynthetic area. Nitrogen is a chlorophyll component that promotes vegetative growth [31]. Sulfur, being a major nutrient, might have played an important physiological role by enhancing leaf expansion [34]. Nitrogen increases shoot and leaf area in cereals and legumes [35].

The increment of the leaf area by lime application might be due to improving soil physical and chemical properties such as reducing soil compaction and soil acidity, increasing infiltration rate, and enhancing soil microbial activities [36].

3.1.2. Plant Height (cm). The main factors' effect was significant ($p < 0.001$) on plant height. And among the effect of the interactions, the interaction of lime rate with rhizobium and lime rate with the NPSB fertilizer rate showed a significant difference ($p < 0.05$) in the plant height (Table 3). The tallest and the shortest plant heights were recorded from rhizobium inoculation (500 g ha^{-1}) and 4t lime ha^{-1} and no rhizobium as well as no lime, respectively (Table 3).

The application of 4 *t* lime ha^{-1} and 180 kg·ha^{-1} NPSB showed the highest plant height, which is statically at par with 4 t lime ha^{-1} and 120 kg·ha^{-1} NPSB, whereas the lowest plant height was recorded from the plot that received none of lime and fertilizer (Table 3). This might be due to the role of applied lime that increases soil microorganisms' activity such as rhizobia and nutrient availability to the crop [37]. Getachew and Angaw [38] also reported a significant enhancement of plant height by P application in faba bean on acidic Nitisols of the central highlands of Ethiopia. In line with this result, Nebret and Nigussie [39] reported that increasing the N level from 0 kg·ha^{-1} to 23 kg·ha^{-1} increased the plant height of the common bean. Fontenele *et al.* [40] found that lime application increased the plant height of cowpea.

Table 2: Treatment combination.

No.	NPSB fertilizer (kg ha⁻)	Lime (t ha^{-1})	Rhizobium
1	0	0	Not inoculated
2			Inoculated
3		2	Not inoculated
4			Inoculated
5		4	Not inoculated
6			Inoculated
7	60	0	Not inoculated
8			Inoculated
9		2	Not inoculated
10			Inoculated
11		4	Not inoculated
12			Inoculated
13	120	0	Not inoculated
14			Inoculated
15		2	Not inoculated
16			Inoculated
17		4	Not inoculated
18			Inoculated
19	180	0	Not inoculated
20			Inoculated
21		2	Not inoculated
22			Inoculated
23		4	Not inoculated
24			Inoculated

3.1.3. Number of Leaves per Plant. The ANOVA result showed that the number of leaves per plant of faba bean was significantly ($p < 0.001$) influenced by the main factors (Tables 3 and 4). But all the interaction effects were none significant. The highest leaf number per plant was obtained from 4 t lime ha^{-1} and 180 kg NPSB ha^{-1}, while the lowest leaf number per plant was obtained from the respective control treatments (Tables 3 and 5). On the other hand, the application of rhizobium inoculation resulted in the highest number of leaves per plant as compared to those without the inoculation of rhizobium (Table 5).

The plot that received 500g ha^{-1} rhizobium inoculation resulted in the highest number of leaves per plant, while the treatment that was not inoculated gave the lowest number of leaves per plant (Table 4). The study by Mmbaga *et al.* [41] with climbing bean varieties inoculated with rhizobium and fertilized with phosphorus showed an increased number of leaves per plant. Mmbaga *et al.* [41] revealed that the number of leaves per plant increased by 20% four weeks after planting. Phosphorus, nitrogen, sulfur, and boron and their interactive effect with rhizobium improve plant growth [42].

3.1.4. Effective Nodules. The effective nodule was significantly ($p < 0.001$) influenced by the main factors and their interaction. The highest percentage of effective nodules per plant was recorded in the treatment that received 4 *t* lime ha^{-1}, 60 kg ha^{-1} NPSB, and 500 g ha^{-1} rhizobium, while the lowest percentage of effective nodules per plant was recorded in the treatment that received 2 *t* lime ha^{-1} and 120 kg·ha^{1} NPSB, without inoculation, and it was statically similar with treatment that received 2 *t* lime ha^{-1} and 180 kg·ha^{-1} NPSB without inoculation (Table 4).

Inoculation of rhizobium strain significantly increased the percentage of effective nodules per plant in contrast to noninoculated seeds. The highest percentage of effective nodules was obtained at the lower fertilizer rate of 60 kg NPSB ha^{-1}. However, a lower percentage of effective nodules was recorded when 120 kg and 180 kg NPSB ha^{-1} without inoculation were applied. This result indicated that higher doses of chemical fertilizer, particularly nitrogenous, suppress the effectiveness of the nodulation of legumes [43, 44]. Plants most susceptible to infection and capable of producing effective nodules should have greater potential to fix more atmospheric N_2 [45].

Singleton et al. [46] reported that, in addition to the nodule formation, the deficiency of phosphorus in legumes also markedly reduced the development of effective nodules. Liming significantly increased nodule number, nodule volume, and nodule dry weight per plant as compared to the un-limed treatment in legume crops [47]. Liming acidic soils enhance the activities of beneficial microbes in the rhizosphere and hence improve root growth. Sulfur application (20–60 kg ha^{-1}) significantly increased the effective number of nodules over no sulfur application, and the total nodules increased with the increasing sulfur application. Several studies have reported that the application of P along with rhizobium inoculant influenced nodulation and N fixation of legume crops [48]. Yoseph [49] reported that the application of P and rhizobium inoculation had a positive effect on the nodulation of the common bean. The study conducted by Zafar et al. [50] to investigate the influence of integrated P supply and plant growth-promoting rhizobacteria on growth, nodulation, yield, and nutrient uptake in Phaseolus vulgaris indicated that P fertilizers di-ammonium phosphate and triple superphosphate each at a rate of 60 kg ha^{-1} increased plant height and nodulation.

3.2. Yield

3.2.1. Aboveground Dry Biomass (kg Ha^{-1}). The main factors and their interaction effect were significantly ($p < 0.001$) influenced the aboveground dry biomass. The highest aboveground dry biomass was obtained from the combined application of 2 *t* lime ha^{-1}, 180 kg NPSB ha^{-1}, and rhizobium inoculation, which was statically similar to the treatments that received 4 *t* lime ha^{-1}, 120 kg NPSB ha^{-1}, and rhizobium inoculation, as well as 2 *t* lime ha^{-1} and 120 kg NPSB ha^{-1} and rhizobium inoculation, whereas the lowest aboveground dry biomass was obtained from the absolute control treatment (Table 4).

The enhancement of the aboveground dry biomass production might be owing to the integrated nutrient management. Liming improves the soil's physical, chemical, and biological properties. This might have resulted in an adequate supply of micro (N and P)- and micronutrients, which could have increased vegetative growth such as the number of branches per plant and leaf area. Thus, the enhanced branching and high leaf area increased the photo interception and thereby improved dry matter accumulation. In line with this result, Fageria *et al* [51] reported

Table 3: Interaction effect of lime and NPSB and lime and rhizobium on the leaf area and main effects of NPSB and rhizobium on the number of leaves per plant of faba bean grown at Kiremu district (during 2019 cropping season).

	Leaf area (cm2)			Plant height (cm)			
NPSB (kg ha-1	Lime (t ha-1)						Number of leaf per plant
	0	2	4	0	2	4	
0	3.94f	6.67e	9.36cd	43.20e	57.47d	61.27cd	24.24c
60	7.02de	8.57cde	10.82bc	58.63d	67.73c	84.27b	30.31b
120	7.01e	13.39a	13.27a	66.57c	88.50ab	92.97a	32.00a
180	7.75de	13.66a	12.53ab	66.87c	90.87ab	95.50a	32.31a
F-test		*			*		***
CV		21.22			8.49		6.77
Rhizobium							
No inoculation	6.29c	8.97b	9.90b	57.7d	68.7c	72.30c	28.57b
Inoculated	6.56c	12.18a	13.09a	59.9d	83.6b	94.7a	30.87a
F-test	*	***	***				
CV (%)	21.22	8.49	6.77				

Means within columns and rows followed by the same letter (s) are not significantly different at a 5% level of significance; CV = coefficient of variation.

significantly increased straw and grain yield resulting in high aboveground biomass of soybean. Similarly increased dry matter production of legumes in response to adequate application of fertilizers was reported [34, 52, 53]. The integrated nutrient management could also have improved the N derived from symbiotic N_2 fixation, which improves vegetative growth and dry matter accumulation [36, 54, 55].

3.2.2. Grain Yield (kg Ha^{-1}). The application rates of blended NPSB fertilizer, lime, and rhizobium inoculation, as well as their interactions, were significantly ($p < 0.001$) affected the grain yield of faba bean. The highest (2405.67 kg) grain yield was obtained from the application of 4 *t* lime ha^{-1},120 kg NPSB ha^{-1}, and rhizobium inoculation, while the lowest (864 kg) grain yield was obtained from treatment with no fertilizer and lime but inoculated with rhizobium and par with the absolute control treatment (Table 4).

The grain yield enhancement observed due to the combined application of lime and NPSB and rhizobium might be related to the nutrient supply that helped the crop vegetative growth to improve photo interception and thus high dry matter partition to grain. Liming is reported to significantly increased straw and grain yield and yield components in soybean [52]. The multiple positive effects of lime on the physical, chemical, and biological properties of soils are also reported to contribute to crop growth and increase grain yield [36]. The synergetic effect of liming, chemical NPSB fertilizer, and rhizobium inoculation was reported by Favaretto *et al.* [56]. Zewde [57] reported that NPSB application up to 69 kg P_2O_5 ha^{-1} resulted in an increased grain yield. The integrated use of rhizobium inoculation and chemical blended fertilizers helps the supply of balanced nutrients to nutrient-deficient soils resulting in improved production of the crop [58].

3.2.3. Harvest Index (%). The harvest index is useful in measuring nutrient partitioning in crop plants, which indicates how efficiently the plant utilized acquired nutrients for grain production. The highest harvest index infers higher partitioning of photosynthates to grain. The harvest index of faba bean was significantly ($p < 0.001$) affected by the main effect of lime and NPSB rate and rhizobium inoculation as well as their interaction (Table 5). The result showed that the plot supplied with 4 *t* lime ha^{-1} and 120 kg NPSB ha^{-1} and inoculated with rhizobium gave the highest harvest index and at par with 2 *t* lime ha^{-1} and 120 kg NPSB ha^{-1} and inoculated with rhizobium, while the only rhizobium inoculated treatment gave the lowest harvest index, which is at par with the control treatment (Table 4).

The possible reason for the high harvest index at the application of 4 *t* lime ha^{-1} and 120 kg NPSB ha^{-1} and inoculated with rhizobium could be related to the improved grain yield at the aforementioned combination and rates of fertilizers. In conformity with this result, Shiferaw and Anteneh [59] found the application of lime and combinations of fertilizers (NPSB) significantly increased barley yield over the control treatment. Abdulkadir *et al.* [60] and Rafat and Sharif [61] reported that a balanced nutrient supply improves crop yield and thus the harvest index. Ivarson [62] also reported that lime application to acidic soils due to its effect on soil physicochemical properties could result in improved plant nutrition and then harvest index.

3.3. Yield Components

3.3.1. Hundred Seed Weight (g). The main factors and their interaction effects were significant ($P < 0.05$) on a hundred seed weight (Table 5). The highest hundred seed weight was recorded from the treatment that received 4 *t* lime ha^{-1}, 120 kg NPSB ha^{-1}, and rhizobium inoculation, whereas the lowest 100 seed weight was recorded in the treatment that was not limed and fertilized but only rhizobium inoculated (Table 4). The highest seed weight obtained at the medium rate of blended fertilizer rate, highest lime rate, and rhizobium inoculation in this experiment could be due to a balanced nutrient supply, which aided the formation and translocation of photosynthesis to the reproductive part, thus leading to increased seed size. This indicates that the synergistic effect of

Table 4: Effects of lime, NPSB, and rhizobium interactions on the effective nodule, aboveground biomass, grain yield, harvest index, and 100 seed weight of faba bean.

NPSB (kg ha^{-1})	Lime (t ha-1)	Rhizobium	EN (%)	Agbm (kg ha^{-1})	GY (kg ha^{-1})	HI (%)	HSW (g)
0	0	Not inoculated	54.73^{i}	2000.3^{h}	866.3^{m}	24.1^{k}	63.7^{hij}
		Inoculated	55.83^{hi}	2056.3^{h}	864.0^{m}	21.0^{k}	54.2^{k}
	2	Not inoculated	58.73^{h}	2729.3^{f}	1182.0^{jk}	30.8^{j}	63.1^{ij}
		Inoculated	77.13^{de}	2282.3^{gh}	1219.7^{ij}	43.7^{defg}	62.8^{ij}
	4	Not inoculated	64.13^{g}	2807.0^{f}	1240.0^{ij}	37.3^{hi}	61.6^{j}
		Inoculated	74.87^{e}	2879.7^{f}	1250.0^{i}	40.1^{gh}	67.6^{gh}
60	0	Not inoculated	70.47^{f}	2571.3^{fg}	1113.3^{l}	32.5^{ij}	64.4^{ghij}
		Inoculated	75.80^{de}	2598.0^{fg}	1148.0^{kl}	37.6^{hi}	64.9^{ghij}
	2	Not inoculated	74.27^{ef}	2829.3^{f}	1232.7^{ij}	43.0^{fgh}	68.5^{efg}
		Inoculated	81.42^{bc}	3337.3^{e}	1458.7^{h}	44.2^{defg}	71.91^{def}
	4	Not inoculated	82.47^{abc}	3370.0^{e}	1453.0^{h}	43.5^{efg}	63.1^{ij}
		Inoculated	85.68^{a}	4772.3^{b}	2061.0^{c}	41.9^{fgh}	$77.^{bc}$
120	0	Not inoculated	76.20^{de}	3486.0^{e}	1509.7^{gh}	39.4^{gh}	66.5^{ghi}
		Inoculated	79.00^{cd}	3498.3^{e}	1525.7^{g}	$44.4d^{efg}$	$66.^{ghi}$
	2	Not inoculated	24.00^{k}	3871.0^{cd}	1767.7^{e}	49.2^{bcde}	66.4^{ghi}
		Inoculated	83.07ab	5410.7^{a}	2343.3^{b}	62.9^{a}	72.3^{de}
	4	Not inoculated	76.760^{de}	3840.3^{cd}	1661.0^{f}	52.1^{b}	62.7^{ij}
		Inoculated	75.07^{de}	5547.7^{a}	2405.7^{a}	68.3^{a}	83.9^{a}
180	0	Not inoculated	35.00^{j}	3572.7^{de}	1547.3^{g}	49.0^{bcde}	$67.^{9fg}$
		Inoculated	35.54^{j}	3602.7^{de}	1557.7^{g}	46.3^{cdef}	55.7^{k}
	2	Not inoculated	25.33^{k}	4161.7^{c}	1778.0^{e}	49.3^{bcd}	74.4^{cd}
		Inoculated	75.30^{de}	5551.3^{a}	1897.3^{d}	64.6^{a}	74.7^{cd}
	4	Not inoculated	58.30^{hi}	3858.0^{cd}	1663.3^{f}	51.0^{bc}	$66.^{ghi}$
		Inoculated	54.53^{i}	4891.3^{b}	2086.0^{c}	43.0^{fgh}	80.3^{ab}
F-test				***	***	***	*
CV (%)				3.75	2.44	7.98	3.86

Means within columns followed by the same letter (s) are not significantly different at a 0.05% level of significance; NPSB 18.9% N, 37.7% P, 6.95% S, and 0.1% B: CV= coefficient of variation; ABGM = aboveground biomass, GY = grain yield, HI = harvest index, EN = effective nodule.

Table 5: Interaction effects of the NPSB rate with the lime rate on the number of seeds per pod and lime with rhizobium on the number of pods per plant and main effects of lime on number of leaves per plant of faba bean grown at Kiremu (during 2019 cropping season).

Treatment	Number of seeds per pod				Rhizobium		Number of leaves per plant
	NPSB (kg ha^{-1})						
Lime (t ha^{-1})	0	60	120	180	Not inoculated	Inoculated	
0	1.67^{f}	2.25^{e}	2.62^{cd}	2.67^{c}	10.4^{d}	10.7^{d}	24.96^{c}
2	2.22^{e}	2.65^{c}	2.9^{ab}	2.87^{ab}	13.2^{c}	16.7^{b}	31.44^{b}
4	2.45^{d}	2.77^{bc}	2.97^{a}	2.9^{ab}	16.2^{b}	22.0^{a}	32.75^{a}
F-test	**				***		***
CV (%)	5.79				12.02		6.77

Means within columns and rows followed by the same letter (s) are not significantly different at a 1% level of significance; NPSB 18.9% N, 37.7% P, 6.95% S, and 0.1% B: CV = coefficient of variation.

applied lime together with the rate of organic and inorganic fertilizers gave the highest productivity [63].

3.3.2. Number of Seeds per Pod and Number of Seeds per Plant. The main effect of lime, NPSB rate, and rhizobium inoculation as well as the interaction of lime and NPSB rate were significant ($P < 0.001$) on the number of seeds per pod. The highest number of seeds per pod was obtained from the application of 120 kg NPSB ha^{-1} and 4 t ha^{-1} lime, whereas the lowest number of seeds per pod was obtained from the control treatment (Table 5).

The increased seed per pod might be due to the synergic effects of lime, blended NPSB fertilizer, and rhizobium inoculation that improved the crop nutrition subsequently leading to grain formation and grain filling. Liming improves the nutrient availability especially P in acidic soils and P is more important for grain formation and development [36]. Similarly, Zafar et al. [63] reported the importance of P in photosynthates translocation and dry matter partition to the economic part of grain, which could be explained as seed per pod. Meena *et al.* [64] also reported that P fertilization improved seed per pod of chickpea.

The main effect of lime and NPSB fertilizer rate, and rhizobium inoculation as well as the interaction of lime rate with rhizobium inoculation were significant on ($P < 0.001$) the number of pods per plant. The highest number of pods per plant was obtained from the application of 4 t lime ha^{-1}

Table 6: Results of the economic analysis for the combined application of blended fertilizer (NPSB), lime, and inoculation in faba bean at the Kiremu district.

Treatments	TVC (ETB ha-1)	AGY (Kg ha-1)	GFB (ETB ha-1)	NB (ETB ha-1)	MRR (%)
0 t L ha^{-1} + 0 NPSB ha^{-1} + NI	0	779.7	24170.61	24,171	_
0 tL ha^{-1} + 60 NPSB ha^{-1} + NI	1339	1001.8	31061.91	29722	415
0 t L ha^{-1} + 60 NPSB kg ha^{-1} + 500g ha^{-1} IN	1829	1033.2	32029.2	30200	97
2 t L ha^{-1} + 0 NPSB kg ha^{-1} + NI	2000	1063.8	32977.8	30,978	455
0 t Lha^{-1} + 120 NPSB kg ha^{-1} + NI	2278	1358.7	42119.39	39841	3188
0 t Lha^{-1} + 180 NPSB kg ha^{-1} + NI	3217	1392.6	43170.29	39953	40
2t L + 120 NPSB kg ha^{-1} NI	4278	1590.9	49317.59	45,040	479
2 t L ha^{-1} + 120 NPSB kg ha^{-1} + 500 g ha^{-1} IN	4768	2109	65378.07	60610	3178

with 500 g·ha^{-1} rhizobium inoculation, while the lowest number of pods per plant was obtained from the respective control treatment (Table 5). Pod number per plant was significantly higher in limed soils sown with rhizobium inoculated seeds.

This might be due to biological N fixation by rhizobium inoculation adding N and liming, which improves P, Ca availability to the crop as also reported by Cigdem Kucuk [65]. The N and P supply increased leaf area, which is positively associated with more reproductive nodes and thus increased pods per plant. This result agrees with the finding of Amare et al. [66] who reported P application significantly increased the pod per plant. Likewise, Yoseph [67] revealed the important contribution of biologically fixed N and P in enhancing growth and assimilate accumulation, thereby improving the reproductive performance pod per plant.

4. Economic Analysis

The net benefit realization of the treatment was estimated using a mean open market price of the dry pod yield at farm gate per kg, the variable costs related to the treatment following procedures of CIMMYT [33]. Based on the partial budget procedure described by CIMMYT [33], the variable costs included the NPSB fertilizer cost (16.30 ETB kg^{-1}) and biofertilizer cost (160 ETB ha^{-1}), and lime price (1 ETB kg^{-1}) at time of planting. The field gets an average market price of grain yield (adjusted downward by 10%) of faba bean of 31 ETB kg^{-1}. The dominance analysis was undertaken to select potentially profitable treatments from the range tested, and thus, the nondominated treatments presented in Table 6 showed the potentially profitable treatments for which MRR analysis was conducted.

The budget summary of the economic analysis is presented in Table 6. The highest net return (60610 ETB ha^{-1}) was obtained from rhizobium inoculation with NPSB 120 kg ha^{-1} and 2 t lime ha^{-1} with a marginal rate of return of 3178% followed by a net benefit of 45,040 ETB ha^{-1} with MRR 479% at rhizobium inoculation with NPSB 120 kg ha^{-1} and 4 t lime ha^{-1}, while the lowest net benefit of 24,171 ETB ha^{-1} from 0 NPSB, 0 t lime, and rhizobium inoculation (Table 6). In agreement with this result, Zewude [68] reported the highest net benefit of 60610 ETB ha^{-1} with a marginal rate of return (MRR) of 2528.7% with the combination of 120 kg NPSB ha^{-1}, 2 t lime ha^{-1}, and rhizobium inoculation [57]. L = lime; IN = inoculated; NI= not inoculated; AGY = adjusted grain yield; GFB = gross field benefit; TVC = total variable costs; NB = net benefit; MRR = marginal rate of return; ETB ha^{-1} = Ethiopian Birr per hectare.

5. Conclusion

The present result has shown that faba bean yield and yield components were significantly affected by the treatment. The highest grain yield, harvest index, and 100 seed weight were obtained from the combined application, which received 120 kg NPSB ha^{-1}, 4 t lime ha^{-1}, and inoculation of 500 g rhizobium ha^{-1}. Generally, from the results of the current study, it can be pointed out that among treatments tested, the application of 120 kg NPSB ha^{-1}, 2 t lime ha^{-1}, and 500 g rhizobium ha^{-1} inoculation can be considered the most preferable alternative for maximizing productivity and profitability of faba bean production in the study area. The application of 120 Kg NPSB ha^{-1} without liming and inoculation can also be considered the next alternative in areas where there is no accessibility of lime and rhizobium inoculum for the producers. Although the results of the present study were promising, further work is required to promote the application of different rates of lime, NPSB, and rhizobium inoculation to faba bean under different agroecologies and seasons.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding this article.

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