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Research Article

Short-Term Integrated Application of Nitrogen, Phosphorus, Sulfur, and Boron Fertilizer and the Farmyard Manure Effect on the Yield and Yield Components of Common Bean (*Phaseolus vulgaris* L.) at Alle Special Woreda, Southern Ethiopia

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In Ethiopia, the common bean (*Phaseolus vulgaris* L.) is an important grain legume with a high food and commercial value. Yet, its productivity is very low, which could be attributed to low levels of soil organic matter, nitrogen (N), phosphorous (P), sulfur (S), and boron (B), and insufficient fertilizer application. Therefore, a field experiment was conducted during the 2019 cropping season in Alle, Southern Ethiopia, to evaluate the agronomic and economic responses of blended NPSB (18.7N-37.4P2O5-6.9S-0.25B) and farmyard manure (FYM) for common bean production. Four NPSB-blended fertilizer rates (0, 50, 100, and 150 $kg{\cdot}ha^{-1}$) and three FYM rates (0, 2.5, and 5 $tons{\cdot}ha^{-1}$) were used in the experiment. The experiment was laid out using a randomized complete block design in a factorial arrangement with four replications. The result showed that NPSB and FYM significantly affected crop phenology, growth, yield, and yield components. Application of 100 $kg{\cdot}ha^{-1}$ NPSB along with 5 $t{\cdot}ha^{-1}$ FYM significantly increased the number of nodules, hundred seed weight, and grain production. The results also showed that using 100 $kg{\cdot}ha^{-1}$ NPSB fertilizer in combination with 5 $t{\cdot}ha^{-1}$ FYM produced the highest grain, which is about 173% higher grain yield than the control. Partial budget analysis indicated that application of 100 $kg{\cdot}ha^{-1}$ NPSB fertilizer with 5 $t{\cdot}ha^{-1}$ FYM resulted in the highest marginal rate of return (1308%) and the best net profit. Therefore, an integrated application of 100 $kg{\cdot}ha^{-1}$ NPSB fertilizer and 5 $t{\cdot}ha^{-1}$ FYM is suggested.

1. Introduction

Common bean (*Phaseolus vulgaris* L.) belongs to the Fabaceae family and is a large grain legume whose edible seeds and pods have been consumed all over the world. Ethiopian farmers have a preference to produce it because of its early maturing properties, which allow households to obtain financial resources needed to purchase food and other household necessities, while other crops have not yet developed [1]. As a result, it gives a financial benefit to small holding farmers as an alternative source of protein and money to help them improve their food security [2]. The ability of the common bean to fix nitrogen (N) has raised the crop's importance in terms of boosting soil fertility. Common beans also contain chemicals that may help to prevent sickness and promote good health [3]. According to Leteme and Munoz [4], health organizations should promote frequent consumption of common beans because it lowers the risk of diseases including cancer, diabetes, and coronary heart disease. This is due to the fact that common beans are cholesterol-free and low in fat.

Oromia and the Southern Nation Nationalities and Peoples Region (SNNPR) are Ethiopia's largest common bean producing regions, accounting for 69.05% (337,160.86 tons) of the country's total production [5]. According to CSA [5], the 2018/2019 main cropping season's area coverage, production, and national average yield of common bean in Ethiopia were 288,637.23 ha^{-1}, 488,320.17 t, and

$1.69\ t{\cdot}ha^{-1}$, respectively. The average yield in SNNPR was $1.57\ t{\cdot}ha^{-1}$. The average yield in Alle Special Woreda (i.e., study area) was $1.05\ t{\cdot}ha^{-1}$ (Alle Woreda Agriculture Office, 2019 unpublished report). However, the yield recorded at various scales falls well below the potential of 2.5–4 $t{\cdot}ha^{-1}$ research areas [6]. Lower crop yields could be related to a decline in soil fertility. Deficiencies of key nutrients (both macro and micro) have been identified as one of the main causes of crop yield loss and unsustainable agricultural production in Ethiopia [7–9]. For instance, soil fertility mapping by Ethio SIS (8) revealed low levels of nitrogen (N), phosphorus (P), sulfur (S), boron (B), and zinc (Zn) in most bean-growing areas of Alle Woreda (Zn). Continuous farming of the same land year after year, insufficient replenishment of lost nutrients, total residue clearance from the field, and soil erosion are all blamed for the deficiencies [9].

The use of organic and inorganic fertilizers as well as their integration can be used to alleviate soil nutrient depletion problems. Inorganic fertilizers are commonly regarded as a viable solution to the problem of soil nutrient depletion and food production sustainability. The major fertilizers used by farmers in Ethiopia have been limited to urea (46N-0-0) and diammonium phosphate (DAP) (18N-46P_2O_5-0), which supply only N and P, which may not meet the nutrient requirements of the crop, creating nutrient imbalances in soils [10]. To address the problem, the Ethiopian government has introduced a new mixed fertilizer (e.g., NPSB (19.7N-37.4P_2O_5-6.9S-0.25B)) based on the national soil fertility survey results [7, 8]. Mineral fertilizers are still underutilized in terms of application rates, timing, and fertilizer selection due to their high cost to small-scale farmers, as well as lack of information and training. Aside from that, using mineral fertilizers alone has negative consequences for soil microbes and the environment [11].

From an economic standpoint, the utilization of organic nutrient sources such as fertilizer in less developed nations like Ethiopia has got a lot of attention. The effort to identify and develop efficient strategies for using organic nutrient sources as fertilizer is urgently needed, given the current global shortage of chemical fertilizers and their expected negative impact on food supply. However, due to limited accessible nutrients, relatively low nutrient content, high application rates, and high labor requirements, organic fertilizer alone may not be able to adequately meet crop nutrient demand unless it is combined with inorganic fertilizers [12].

Soil fertility and productivity require the use of both organic and inorganic fertilizers. Furthermore, the use of integrated nutrient management has reduced the cost of mineral fertilizer by more than half [13]. In view of this, different scholars have reported remarkable results from the integrated application of organic and mineral fertilizers, including common bean [11, 14, 15]. For example, Fouda et al. [14] recorded the highest grain yield values of 1681.12 (g) per plot for common bean following an integrated application of NPK 100% + compost. Zahida et al. [16] also observed a 173.8% increase in grain yield over the control due to the integration of NPK and FYM. Further, Elka and Laekemariam [11] reported a 312% grain yield gain advantage over the control in response to integrated application of 150 kg $NPS{\cdot}ha^{-1}$ and 2.5 t organic material from *Croton* (*Croton macrostachyus*) and *Erythrina* (*Erythrina brucei*).

Besides, integrated application of inorganic nutrients with organic nutrients improves soil chemical properties [17–19]. For instance, Jibril and Bekele [19] reported that the higher total nitrogen (26%), available phosphorus (3.57%), and sulfur (4.36%) were obtained from a combined application of 7.5 t of coffee husk compost and 112.5 kg of $NPSB{\cdot}ha^{-1}$. Furthermore, Tana and Woldesenbet [18] recorded that the application of 5 t $FYM{\cdot}ha^{-1}$ along with 75% recommended rates of inorganic N and P (17.25 kg $N{\cdot}ha^{-1}$ and 34.5 kg $P_2O_5\ ha^{-1}$) was found to be superior and increased soil organic carbon content by 36 and 44.6%, available phosphorus by 70.5 and 78.2%, and available potassium by 42.5 and 26.3%. Meanwhile, in Alle Woreda, where this study was conducted, farmers have had high access to FYM as livestock production takes a major share of the farming system. Yet, the use of FYM as a fertilizing material is limited. Moreover, information on the effect of FYM application along with the recently introduced mineral NPSB (19.7N-37.4P_2O_5-6.9S-0.25B) fertilizer on the growth, yield, and yield components of common bean is lacking. Therefore, this research was initiated with the objectives of determining the optimum rate of NPSB and FYM combination and their interaction for maximum common bean production and assessing the economic feasibility and profitability of NPSB and FYM use for common production.

2. Materials and Methods

2.1. Description of Experimental Area. A field experiment was conducted during the 2019 agricultural season at the Wolanigo Farmers Training Center field in the Alle Special Woreda in Southern Ethiopia (Figure 1). The site's approximate geographic location is 50° 29′ 56″ N latitude and 370° 12′ 39″ E longitude, at an altitude of 1730 masl. The average annual rainfall in the area is 1200 mm, with a bimodal rainfall distribution. The minimum and maximum temperatures were 16 and 27 degrees Celsius, respectively. Maize (*Zea mays*), common bean (*Phaseolous vulgaris* L.), and teff (*Eragrostis tef*) are the main crops farmed in the area. The soil texture of the experimental site is clay.

2.2. Treatments and Experimental Design. Four rates of blended NPSB (0, 50, 100, and 150 $kg{\cdot}ha^{-1}$) and three rates of farmyard manure (0, 2.5, and 5 $t{\cdot}ha^{-1}$) were combined in a factorial arrangement and set out in a randomized complete block design (RCBD) replicated four times. Each plot was 3.2 m wide and 3 m long, with a gross plot area of 9.6 m^2, and each plot has eight rows of common bean. The test crop was the common bean variety Nasir, which has an intermediate growth habit, dark red seed color, small seed size, days to flowering of 50–57 days, and a maturity of 88–95 days. Melkasa Agricultural Research Center released the bean variety as a food category bean in 2003. The chemical

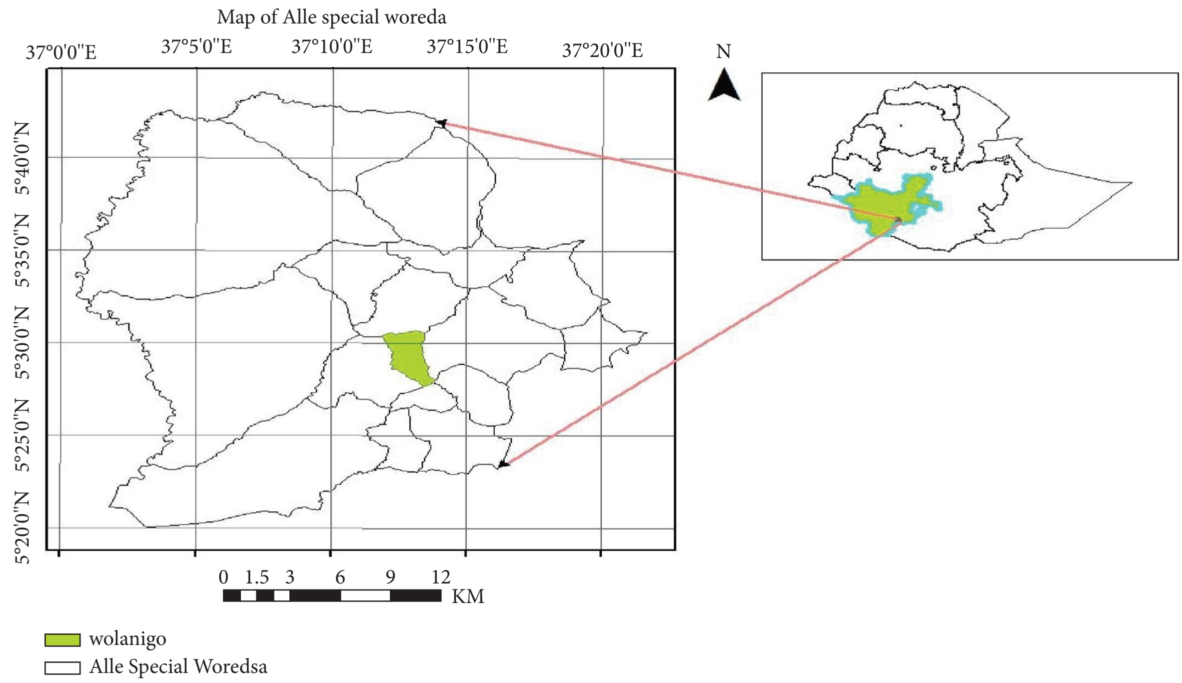

FIGURE 1: Location map of the study area.

composition of blended NPSB (18.7N-37.4P_2O_5-6.9S-0.25B) and FYM is indicated in Table 1. The chemical properties of FYM were determined to be moderate and encouraging in general to use as soil amendment.

TABLE 1: Chemical properties of farm yard manure (FYM).

pH	OC (%)	TN (%)	Available P (ppm)	C : N
8.8	3.32	0.186	23.2	17.8

TN, nitrogen; OC, organic carbon; P, phosphorus.

2.3. Agronomic Practice. The experimental field was oxen ploughed, pulverized, and leveled in order to have a smooth seed bed for planting. Seeds were planted by hand, two seeds per hill, and then thinned following emergence to maintain the desired plant density per acre. The seeds were planted at a row spacing of 40 cm and a plant spacing of 10 cm. When planting was carried out following the planting time, the rated amount of NPSB fertilizer was applied to each plot at planting. Farm yard manure (FYM) is applied by incorporating it into the soil of each plot four weeks before planting. All crop management practices such as cultivation and weeding are carried out as per recommendations for common bean.

2.4. Data Collection and Measurements

2.4.1. Soil Sampling and Analysis. Prior to sowing, 10 soil samples were taken in a diagonal pattern with an auger from a depth of 0 to 30 cm and bulked to produce 1 kg composite soil sample. Following normal laboratory procedures, the working sample was tested for particle size distribution, soil pH, organic carbon, total N, available P, cation exchange capacity (CEC), and available K, B, and SO_4^- S. The soil analysis was conducted at the Areka Agricultural Research Center Soil Laboratory, Ethiopia. The Bouyoucos hydrometer method was used to examine the texture of the soil [20]. A pH meter with a glass-calomel combination electrode was used to determine the pH of the soil. The wet combustion method [21] and the wet digesting procedure of the Kjeldahl method [22] were used to determine the organic carbon and total N contents of the soil. The Olsen method was used to extract the available P [23]. After saturating the soil with 1N ammonium acetate (NH4OAc) and replacing it with 1N NaOAc, the cation exchange capacity (CEC) was measured [24]. The ammonium acetate extract method was used to determine exchangeable K using flame photometry [25]. Boron was quantified using the turbid metric method and available S was calculated using dilute HCL [26]. A representative sample of FYM (cow manure degraded for five months in the shade) was collected and examined at the Sodo Soil Laboratory.

2.4.2. Crop Data

(1) Phenological Parameters. Days to 50% flowering (DF): The number of days between emergence and when 50% of the plant population in each plot flowers was recorded.

Days to maturity (DM): The number of days from planting to when 90% of the plants had yellowed pods was recorded.

(2) Growth Parameters. Plant height (cm): At full bloom, the height of five randomly chosen plants was measured with a meter from the ground level to the tip of the main stem. Leaf area (cm^2) was measured at Hawassa University College of Agriculture, Crop Physiology and Seed.

Technology laboratory using a destructive sample of five plants from each plot using a leaf area meter (Model LI-3000A). The leaf area index (LAI) was determined as the ratio of total leaf area to the crop's related ground area:

$$\mathrm{LAI} = \frac{\text{Total leaf area}}{\text{Ground area}}. \quad (1)$$

The number of primary branches per plant was calculated by counting the number of primary branches on the main stem of five plants chosen at random. The total number of nodules was calculated by averaging the number of nodules on five randomly selected plants from destructive rows in each plot.

(3) Yield and Yield Components. The number of pods per plant was determined by counting the number of pods from five randomly selected plants in each plot, and then the average was taken. The number of seeds per pod was also determined by counting the number of seeds per plant from five randomly selected plants in each plot, and then the average was taken. A random sample of 100 seeds from each plot was used to estimate the weight of a hundred seeds (g). Above ground, dry biomass yield (kg·ha^{-1}) was calculated by destructive sampling of the above ground plant components from five randomly selected sample plants in a row left for destructive sampling at physiological maturity and converted to a hectare basis, while grain yield (kg·ha^{-1}) was estimated from the plants in the net plot area. It was adjusted to a 10% moisture level and converted to a hectare basis. The harvest index (HI) was calculated for each plot as the ratio of grain yield to above ground biomass multiplied by 100.

2.5. Economic Analysis. The treatments' economic feasibility was investigated using economic analysis. We employed partial budgeting and marginal analysis as described by CIMMYT [27]. The average grain yield was lowered by 10% to account for the difference between the experimental output and the yield predicted for the same treatment by farmers. For this study, the average fertilizer costs for NPSB and FYM were 14.87 ETB kg^{-1} and 500 ETB ton^{-1}, respectively. The average open market price of common bean grain was 11 EB/kg. The minimum acceptable rate of return (MAR) for a treatment is 100% [27]. It is considered worthwhile for farmers [27]. This enables farmer recommendations to be made based on marginal analysis.

2.6. Statistical Data Analysis. All the measured data were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD according to the general linear model (GLM) of Statistical Analysis System (SAS) version 9.0 software [28]. Mean separation was done using the least significant difference (LSD) at a 5% probability level whenever significant differences among treatment means were detected. A correlation analysis between blended NPSB fertilizer, farm yard manure, grain yield, and yield attributing traits was also conducted using Statistix version 8 [29].

3. Results and Discussion

3.1. Selected Soil Physicochemical Properties. The soil has a clay textural class, with a particle size distribution of 60% clay, 20% sand, and 20% silt (Table 2). The soil pH was 5.22, which is classified as strongly acidic [30]. The soil's OC concentration was 1.95 percent, which was considered medium by Walkley and Black [21]. According to Jackson's [22] classification, the soil had a total N concentration of 0.08 percent, which is classified as the medium level. The available P content was 17.4 ppm, which falls within the medium (10–19 ppm) category [23]. The available K was 59.15 ppm, which is classified as medium [32]. Boron was 0.08 ppm, which is below 0.5 ppm and considered low [32]. The SO_4^- S concentration was 20.2 ppm, which was classified as excessive [32]. According to Jackson's [31] classification, the CEC concentration of the soil was 27.6 cmol (+) kg^{-1}.

As shown in Table 2, the organic carbon and total N concentrations of FYM were 3.32 and 0.186%, respectively. The available P content was 23.2 ppm. The average pH was 8.8 (1 : 2.5 H_2O). Furthermore, the C : N ratio is 17.8, indicating a higher probability of mineralization and release of vital plant nutrients. In FYM analysis, Tana and Woldesenbet [18] reported a C : N ratio of less than 20 (5.52) and a N content of 1.77%.

3.2. Crop Phenology

3.2.1. Days to 50% Flowering. The interaction of NPSB fertilizer rates with FYM exhibited a significant ($P < 0.05$) effect on days to 50% flowering. The longest day to flowering (44.75) was achieved with a 5 t FYM·ha^{-1} rate and no NPSB fertilizer, which is statistically equivalent to unfertilized plots. At 150 kg NPSB·ha^{-1} and 0 t FYM·ha^{-1}, the earliest days to blossom (41.25) were attained (Table 3). The higher availability and supply of P directly from applied NPSB that substantially favors flowering could explain the hastening effects of combined application of NPSB and FYM on days to flowering. In contrast to the findings of this study, Alemu [34] found that the earliest days to 50 percent heading (77.58) were recorded from control treatments of both FYM and NPS, whereas the longest days to 50 percent heading, 80.66 and 80.83, were recorded from the sole application of higher doses of FYM (12 t·ha^{-1}) and NPS (150 kg·ha^{-1}) fertilizers in upland rice crops, respectively.

Plots that received FYM without mineral fertilizer, on the other hand, took longer to reach 50% flowering. This could be linked to luxuriant vegetative growth of the crop due to the applied FYM. In other words, FYM permits the crop to have a longer phase of vegetative growth and flowering, as well as providing better ground cover and reduce water loss through evaporation, allowing for continued crop growth and development.

3.2.2. Days to Physiological Maturity. The interaction effect of NPSB by FYM fertilizer influenced days to physiological maturity considerably ($P < 0.05$). The application of 0 kg NPSB·ha^{-1} with 5 t FYM·ha^{-1} resulted in the longest days to

Table 2: Selected soil physicochemical properties of experimental site.

Parameters	Values	Soil Rating for soil	Reference
Soil chemical			
pH	5.22	Strongly acidic	[30]
OC%	1.95	Medium	[21]
CEC (Cemol (+)/kg)	27.6	High	[31]
TN%	0.08	Medium	[22]
Av.P (ppm)	17.4	Medium	[23]
Av.K (ppm)	59.15	Medium	[32]
B (ppm)	0.08	Low	[32]
SO_4^- S (ppm)	20.2	High	[32]
Particle size distribution			
Clay	60%		
Sand	20%		
Silt	20%		
Texture	Clay		[33]

Table 3: Days to flowering and physiological maturity as affected by NPSB and FYM rates.

Factors		Variables	
NPSB (kg·ha^{-1})	FYM (t·ha^{-1})	Days to flowering	Days to maturity
0	0	44.75^{a}	84.0^{a}
	2.5	44.25^{a-c}	81.5^{b-d}
	5	44.75^{a}	84.25^{a}
50	0	44.5^{a-b}	83.0^{a-b}
	2.5	43.5^{b-d}	80.75^{c-e}
	5	43.5^{b-d}	82.0^{b-c}
100	0	43.75^{a-c}	80.25^{d-e}
	2.5	43.25^{c-e}	81.5^{b-d}
	5	42.25^{e-g}	81.0^{c-e}
150	0	41.25^{g}	79.5^{e}
	2.5	42.5^{d-f}	83.75^{a}
	5	42.0^{f-g}	80.25^{d-e}
LSD (5%)		1.09	1.61
CV (%)		1.75	1.37

physiological maturity (84.25), which is statistically comparable to the unfertilized plot. The application of 150 kg NPSB fertilizer·ha^{-1} without FYM resulted in hastened days to reach physiological maturity (79.5) (Table 3). With higher rates of NPSB and decreased rates of FYM, days to physiological maturity were shortened in general. This could be owing to the synergetic effect of nutrients from applied mineral fertilizer, which hastens bean crop physiological maturity. Higher concentrations of NPSB stimulate early flowering and maturity in haricot bean, implying a stimulatory impact of P on growth hormones, and the presence of S nutrients induces early flowering and maturity.

According to Arega and Mekonnen [35], increasing NPKSB from 0 to 61.5 : 69 : 60 : 10.5 : 0.15 kg·ha^{-1} delayed the number of days needed to reach physiological maturity in common bean. Assefa et al. [36] also observed the delaying impact of combining N and P fertilizer rates in common bean.

Plots that received FYM without mineral fertilizer, on the other hand, took longer to reach 50% flowering. This could be linked to luxuriant vegetative growth of the crop due to the applied FYM. In other words, FYM permits the crop to have a longer phase of vegetative growth and flowering, as well as providing bet and reduce water loss through evaporation, allowing for continued crop growth and development.

3.3. Growth Parameters

3.3.1. Plant Height. The results revealed that NPSB fertilizer application rates had a significant effect on plant height. Plant height increased as NPSB fertilizer rates increased from 0 to 150 kg·ha^{-1}. The tallest plant height (84.67 cm) was reported at an NPSB fertilizer rate of 150 kg·ha^{-1}, followed by an NPSB fertilizer rate of 100 kg·ha^{-1} with a mean plant height of 77.93 cm. Unfertilized plots attained the shortest plant height (73.58 cm) (Table 4). The maximum plant height was reached at the greatest NPSB rate and dropped when NPSB rates decreased. The rise in plant height in response to NPSB could be due to increased availability of N, P, S, and B from blended NPSB, which triggered vegetative growth and cell division, resulting in increased plant height [37]. This result is in line with those of Kisinyo et al. [38] and Moniruzzaman et al. [39], who found that the combined effects of N, P, and S components resulted in an increase in common bean plant height. In addition, Arega and Mekonnen [35] observed an increasing tendency in plant height as the dose of blended NPSBK fertilizer rates was increased.

Furthermore, Shumi [40] found that an increase in NPS application rates resulted in an increase in common bean plant height. Boron application resulted in an increase in common bean plant heights as compared to non-B augmented fertilizer sources [41]. Amany [42] and Caliskan et al. [43] both found that an increase in the amount of N applied to chickpea and soybean plants boosted plant height.

3.3.2. Leaf Area and Leaf Area Index. The interaction of NPSB with FYM resulted in significant differences in leaf area (LA) and leaf area index (LAI). Accordingly, the application of 100 kg of NPSB fertilizer·ha^{-1} with 2.5 t of FYM·ha^{-1} produced the highest LA (1583.7 cm^2) and LAI (3.95), followed by the same rate of NPSB fertilizer with 5 t of FYM·ha^{-1} with a mean LA of 1383.4 cm^2 and LAI of 3.46, while a sole application of 2.5 t of FYM·ha^{-1} resulted in the lowest LA (981 cm^2) and LAI (2.45) (Table 5). The increase in LA and LAI might be attributed to the direct and indirect supply of some of the essential nutrients such as N, P, S, B, and other nutrients to the soil solution. As a result, N supports chlorophyll synthesis, P for unique bonding, which is important in nucleotide-based metabolic processes, and S for improved chlorophyll formation and vegetative growth [39, 44]. Furthermore, an increase in LA and LAI could be attributed to increased nutritional availability, which could have boosted cell division and expansion, resulting in an increase in LA and LAI. Elka and Laekemariam [11] also

Table 4: Plant height as affected by NPSB fertilizer and FYM rates.

NPSB ($kg{\cdot}ha^{-1}$)	Plant height (cm)
0	73.58^{b}
50	75.11^{b}
100	77.93^{b}
150	84.67^{a}
Mean	77.82
LSD (0.05)	6.1
FYM ($t{\cdot}ha^{-1}$)	
0	78.2
2.5	75.1
5	79.9
Mean	77.82
LSD (0.05)	NS
CV (%)	9.49

Table 5: Leaf area, leaf area index, number of primary branches, and number of total nodules per plant as affected by NPSB and FYM rates.

Factors		Variables			
NPSB ($kg{\cdot}ha^{-1}$)	FYM ($t{\cdot}ha^{-1}$)	Leaf area (cm^2)	Leaf area index	Primary branches	Nodules
0	0	$1024.5^{c\text{-}d}$	$2.56^{c\text{-}d}$	2.05^{e}	55.3^{f}
	2.5	981^{d}	2.45^{d}	$2.15^{d\text{-}e}$	47.25^{g}
	5	1168.7^{b-d}	2.92^{b-d}	3.3^{a-c}	52^{f}
50	0	$1062.8^{c\text{-}d}$	$2.65^{c\text{-}d}$	2.05^{e}	117.65^{d}
	2.5	$1082.3^{c\text{-}d}$	$2.71^{c\text{-}d}$	2.95^{b-d}	102.78^{e}
	5	1201.3^{b-d}	3.01^{b-d}	2.75^{b-e}	158^{c}
100	0	$1234.6^{b\text{-}c}$	$3.09^{b\text{-}c}$	2.9^{b-d}	156.95^{c}
	2.5	1583.7^{a}	3.96^{a}	3.1^{a-c}	170.6^{b}
	5	$1383.4^{a\text{-}b}$	$3.46^{a\text{-}b}$	2.65^{c-e}	180.25^{a}
150	0	$1381.8^{a\text{-}b}$	$3.45^{a\text{-}b}$	$3.55^{a\text{-}b}$	179.55^{a}
	2.5	1173.6^{b-d}	2.94^{b-d}	3.9^{a}	169.75^{b}
	5	$1246.1^{b\text{-}c}$	$3.12^{b\text{-}c}$	2.9^{b-d}	168.2^{b}
LSD (5%)		227.26	0.56	0.83	3.71
CV (%)		13.05	13.05	20.27	2.0

recorded the highest LAI (4.49), which was 233 percent higher than the unfertilized condition, from an integrated application of 150 kg $NPS{\cdot}ha^{-1}$ and 5 $t{\cdot}ha^{-1}$ organic fertilizer in common bean. Gyamfi [45] also recorded the greatest LA (0.87 m^2) in a soybean crop in response to a mixture of 45 $kg{\cdot}ha^{-1}$ NPK and 4 $t{\cdot}ha^{-1}$ poultry manure. Furthermore, Zahida et al. [16] found that common bean had the highest LAI in response to an integrated nutrient application of 15 $kg{\cdot}ha^{-1}$ N, 25 $kg{\cdot}ha^{-1}$ P_2O_5, and 15 $kg{\cdot}ha^{-1}$ K_2O + 1.5 $t{\cdot}ha^{-1}$ FYM + 0.55 $t{\cdot}ha^{-1}$ with biofertilizer.

3.3.3. Number of Primary Branches per Plant. The results revealed that interactions between NPSB and FYM had a significant effect on the number of primary branches per plant. Hence, the combined application of 150 kg $NPSB{\cdot}ha^{-1}$ and 2.5 t $FYM{\cdot}ha^{-1}$ yielded the highest number of primary branches per plant (3.9), followed by application of the same rate of NPSB fertilizer yielding at nil rate of FYM resulting in 3.55 (Table 5). Unfertilized plots had the smallest number of primary branches per plant (2.05). Overall, the combination of the highest rate of 150 kg $NPSB{\cdot}ha^{-1}$ with FYM levels produced the best results. The findings are consistent with those of Fekadu et al. [15], who found that combined application of 8 t $FYM{\cdot}ha^{-1}$ with 30 kg $P{\cdot}ha^{-1}$ increased the number of branches per plant in faba bean. Moniruzzaman et al. [39] found that the combined application of N, P, K, S, Zn, and B resulted in a considerable increase in the number of primary branches per plant. In contrast to the findings of this study, Chala and Obsa [46] found that combining P and FYM had no influence on the number of branches per plant in chickpea.

3.3.4. Number of Nodules per Plant. The interaction of NPSB and FYM resulted in significant ($P < 0.05$) variations in the nodule number. The combined application of 100 kg $NPSB{\cdot}ha^{-1}$ and 5 t $FYM{\cdot}ha^{-1}$ produced the highest number of total nodules (180.25), which is statistically comparable to the sole application of 150 kg $NPSB{\cdot}ha^{-1}$ (Table 5). Application of 2.5 $t{\cdot}ha^{-1}$ FYM along with a nil rate of blended NPSB resulted in the lowest number of nodules per plant (47.25). The results clearly showed that combining blended NPSB fertilizer with FYM significantly increased total nodulation in common bean, implying that nutrients from organic and inorganic sources, particularly P, have integrated effects on nodule formation and improved root development and N fixation in common bean [47, 48]. According to Zengeni et al. [49], manure application increases indigenous rhizobium populations, which serve as a source of C and offer a suitable environment for bacterial proliferation. As a result, the increase in nodule number could be attributed to improved soil rhizobium condition as a result of increased P and other micronutrient contents of the soil from farmyard manure application. The present finding is in agreement with the findings of Fatima et al. [50] and Argaw [51], who reported a significantly high nodule number as a result of the application of integrated application of organic and inorganic fertilizer for lentil and peanut, respectively. According to Fatima et al., [50] the highest number of nodules plant^{-1} (7.28) was recorded due to combined application of 50 : 70 : 30 NPK·ha^{-1} along with 4 t FYM·ha^{-1}. Furthermore, Argaw [51] also integrated application of organic (compost and manure) and inorganic fertilizer (urea and DAP) integrated with *Bradyrhizobium* inoculation which significantly improved the nodulation peanut (*Arachis hypogea* L.) in nutrient depleted and sandy soils of at Fedis, Eastern Ethiopia.

3.4. Yield and Yield Components

3.4.1. Number of Seeds per Pod. Application of FYM had a significant effect on the number of seeds per pod. As a result, the maximum number of seeds per pod (4.80) was reported at a rate of 5 t FYM·ha^{-1}, followed by a mean number of seeds per pod of 4.55 at a rate of 2.5 t FYM·ha^{-1}, while unfertilized plots produced the smallest number of seeds per pod (4.47) (Table 6). This could be attributed to the improved availability of N, P, S, and other nutrients, following the application of FYM [18], which play an important role in providing energy for seed development and grain filling. There is also a positive and highly significant association ($r = 0.3165$) between FYM rates and the number of seeds per pod (Table 7).

Furthermore, this could be attributed to a higher C : N ratio, which increased organic matter accumulation, increased microbial activity, improved soil characteristics, improved root proliferation, long-term availability and transportation, and higher concentrations of plant nutrients. This result is consistent with the findings of Dereje et al. [48], who reported that the number of seeds per pod of common bean also significantly responded to a single application of compost at Areka, Southern Ethiopia. Similarly, Mahabub et al. [52] found that when cow dung was applied to mung beans, and the number of seeds per pod was considerably higher than in the control condition. Agegnehu [53] also reported a larger number of seeds per pod due to the treatment of 8 t FYM·ha^{-1}.

3.4.2. Number of Pods Per Plant. The results revealed that interaction between blended NPSB and FYM all had a significant effect on the number of pods per plant. With a mean number of pods per plant of 17.35, the highest (18.95) number of pods per plant was obtained with a combined application of 150 kg NPSB·ha^{-1} and 2.5 t FYM·ha^{-1}, followed by a single application of 5 t FYM·ha^{-1} (Table 8). The application of 50 kg NPSB·ha^{-1} along with 0 t FYM·ha^{-1} resulted in the lowest number of pods per plant (8.9), which is statistically equivalent to the control. There is a positive and strong association between the number of pods per plant and the number of primary branches ($r = 0.686$) and leaf area index ($r = 0.407$) (Table 7). This indicates that the increase in the number of pods per plant might be attributed to improved availability of N, P, S, and Zn nutrients in soil solution supplied by both NPSB and FYM fertilizers, which are important for improved growth and development of the plant [54, 55]. Increased leaf area and dry mass production have also been reported as a result of N and P application [56], enhancing photosynthesis and dry matter production. This in turn might have ultimately contributed to the production of a higher number of pods per plant upon retranslocation into reproductive parts. Plant P also strongly encourages flowering and pod formation [54, 57]. In line with these results, several researchers observed a significant increase in the number of pods per plant over the control due to the combined application of different organic nutrient sources: FYM + P [15]; NPK/ha + 4 t FYM/ha [58] and NPS + organic fertilizer [11]. For instance, Fekadu et al. [15] found that integrating FYM and P increased the number of pods per plant from 3.4 to 9.2 in faba bean plants. According to Elka and Laekemariam [11], application of 150 kg NPS·ha^{-1} + 2.5 t·ha^{-1} organic fertilizer increased the pod number per plant by 227% over unfertilized plots. According to Fatima et al., [50] the highest number of pod plant^{-1} (55.66) for lentil was recorded from the treatment (50 : 70 : 30 NPK/ha + 4 t FYM/ha). Furthermore, in line with this, Armin et al. [59] observed that the maximum numbers of pods plant^{-1}were recorded for mung bean as a result of application of vermicompost and 100% inorganic fertilizer. Mekki [60] also observed that using chemical + biofertilizer + organic as a single treatment resulted in a large increase in pods per plant for faba bean.

Table 6: Number of seeds per pod as affected by NPSB and FYM rates.

NPSB (kg·ha^{-1})	Number of seeds per pod
0	4.64
50	4.56
100	4.51
150	4.71
Mean	4.61
LSD (0.05)	NS
FYM (t·ha^{-1})	
0	4.47^{b}
2.5	4.55^{b}
5	4.80^{a}
Mean	4.61
LSD (0.05)	0.26
CV (%)	7.89

3.4.3. Hundred Seed Weight. The hundred seed weight (HSW) was significantly affected by the two-way interaction effect of FYM and NPSB fertilizer rates (Table 8). The maximum seed weight (27.5 g) was recorded when 100 kg

Table 7: Correlation coefficient (r) values and probability levels for blended NPSB fertilizer, farmyard manure, yield, and yield attributing traits as influenced by blended NPSB and farm yard manure at Alle Special Woreda.

	NPP	BNSPB	ADBY	FYM	GY	NSPP	HSW	BNPP
BNSP	0.4064^{***}							
ADGBY	0.7391^{***}	0.3778^{***}						
FYM	0.4887^{***}	-0.0000^{ns}	0.4957^{***}					
GY	0.5195^{***}	0.7016^{***}	0.5457^{***}	0.3979^{***}				
NSPP	0.2313	0.0386^{ns}	0.2625^{ns}	0.3165^{***}	0.1194^{ns}			
HSW	0.5094^{***}	0.4900^{***}	0.5112^{***}	0.5840^{*}	0.6904^{***}	0.1604^{ns}		
BNPP	0.6865^{***}	0.4398^{***}	0.7391^{***}	0.1338^{ns}	0.4242^{***}	0.1366^{ns}		
LAI	0.4073^{***}	0.4657^{***}	0.3464^{**}	0.1385^{ns}	0.6396^{***}	0.0940^{ns}	0.4322^{***}	0.490^{***}

NPP, number of pods per plant; BNPSB, blended NPSB fertilizer; AGDBY, aboveground dry biomass yield; FYM, farm yard manure; GY, grain yield; NSPP, number of seeds per pod; HSW, hundred seed weight; BNPP, branch number per plant; LAI, leaf area index.

Table 8: Number of pods per plant, hundred seed weight, biomass yield, grain yield, and harvest index as affected by NPSB and FYM rates.

Factors		Variables				
NPSB (kg ha^{-1})	FYM (t·ha^{-1})	Number of pods plant^{-1}	Hundred seed weight (g)	Biomass yield (kg·ha^{-1})	Grain yield (kg·ha^{-1})	Harvest index (%)
	0	9.7^{d}	21.14^{f}	2958^{f}	1013^{f}	$34.31^{c–e}$
0	2.5	$11^{c\text{-}d}$	$24.43^{d\text{-}e}$	$3518^{e\text{-}f}$	1073^{f}	$30.94^{d\text{-}e}$
	5	$17.35^{a\text{-}b}$	$26.05^{a–c}$	$6630^{a\text{-}b}$	1705^{de}	27.39^{e}
	0	8.9^{d}	24.38^{e}	$3368^{e\text{-}f}$	1505^{e}	$44.3^{a–c}$
50	2.5	14.1^{bc}	$25.40^{c–e}$	$6473^{a\text{-}b}$	$1895^{c\text{-}d}$	$30.87^{d\text{-}e}$
	5	$15.7^{a\text{-}b}$	$26.11^{a–c}$	$4683^{d\text{-}e}$	$1708^{d\text{-}e}$	$37.01^{b–e}$
	0	$14^{b\text{-}c}$	24.35^{e}	$5410^{b–d}$	$1900^{c\text{-}d}$	$36.93^{b–e}$
100	2.5	$14.15^{b\text{-}c}$	27.54^{a}	$5078^{c\text{-}d}$	2628^{a}	53.32^{a}
	5	$16.8^{a\text{-}b}$	27.43^{a}	$6228^{a–c}$	2765^{a}	$44.97^{a\text{-}b}$
	0	$14.9^{b\text{-}c}$	$25.78^{b–e}$	$5033^{c\text{-}d}$	$1978^{c\text{-}d}$	$39.93^{b–d}$
150	2.5	18.95^{a}	$25.99^{a–d}$	$5750^{a–d}$	$2228^{b\text{-}c}$	$39.0^{b–d}$
	5	$16.2^{a\text{-}b}$	$27.24^{a\text{-}b}$	6998^{a}	$2450^{a\text{-}b}$	$35.98^{b–e}$
LSD (5%)		4.01	1.61	1319.6	360.35	10.25
CV (%)		19.5	4.41	17.72	13.16	18.8

NPSB and 2.5 t FYM were applied together. This treatment was statistically equivalent to applying the same rate of NPSB fertilizer with 5 t FYM·ha^{-1}, and the unfertilized plots had the lowest HSW (21.1 g). When 100 kg NPSB and 2.5 t FYM·ha^{-1} blended NPSB fertilizer was applied at a rate of 100 kg NPSB and 2.5 t FYM·ha^{-1}, hundred seed weight increased by 23.3 percent (Table 8). There is also a positive and strong relationship between hundred seed weight and blended NPSB rate ($r = 0.490$) and hundred seed weight and FYM ($r = 0.584$) (Table 7). Hence, the increase in HSW with increasing levels of NPSB and FYM could be due to adequate nutrient supply from organic and inorganic fertilizer sources throughout the growing period, minimizing plant exposure to nutrient stress at any stage, improved microbial activity, and a stronger root system, which favors more extensive soil exploration, nutrient mobilization, and uptake efficiency. These in turn may have accelerated metabolic processes, resulting in improved photosynthesis and efficient photosynthate translocation from sink to sources, resulting in higher seed weight.

Furthermore, the positive and strong associations between hundred seed weight and leaf area index ($r = 0.432$) and hundred seed weight and number of primary branches ($r = 0.3138$) indicate the positive contribution of improved growth for higher seed weight (Table 7). Fekadu et al. [15] reported the greatest 1000 seed weight in faba bean as a result of a combined application of 4 t FYM·ha^{-1} and 15 kg P·ha^{-1}. Zahida et al. [16] also reported significantly higher 100 seed weight in the combined use of NPK, FYM, VC, and bio-fertilizer than in the sole application of either of these fertilizers.

3.4.4. Biomass Yield. The interaction of NPSB fertilizer rates and FYM fertilizer rates had a significant effect on biomass yield. The highest biomass yield (6998 kg·ha^{-1}) was obtained as a result of the combined application of 150 kg NPSB·ha^{-1} with 5 t FYM·ha^{-1}, which is 137% greater than the lowest biomass yield (2958 kg·ha^{-1}) obtained by the control (Table 8). Positive and significant associations were also observed between biomass weight and blended fertilizer rate ($r = 0.377$) (Table 7), which indicates that the higher biomass growth with an increase in blended NPSB fertilizer might be attributed to improved availability of essential plant nutrients such as N, P, S, and B indicating the contribution of the essential nutrients for higher growth of the crop. Further, the improved biomass yield might be attributed to better vegetative growth in terms of leaf area index and number of branches per plant, which in turn improves light

Table 9: Profitability as affected by NPSB and FYM fertilizer rates.

NPSB (kg/ha)	FYM (t/ha)	GY (kg/ha)	Adj GY (kg/ha)	GB (ETB)	TVC (ETB)	NB (ETB)	MRR (%)
0	0	1012.5	911.25	10023.8	0.0	10023.8	—
50	0	1505	1354.5	14899.5	743.5	14156	555.8
100	0	1900	1710	18810	1487	17323	426
150	0	1977.5	1779.75	19577.3	2230.5	17346.8	3.2
0	2.5	1072.5	965.25	10617.8	1250	9367.8	—
50	2.5	1895	1705.5	18760.5	1993.5	16767	995
100	2.5	2627.5	2364.75	26012.3	2737	23275.3	875.4
150	2.5	2227.5	2004.75	22052.3	3480.5	18571.8	D
0	5	1705	1534.5	16879.5	2500	14379.5	—
50	5	1707.5	1536.75	16904.3	3243.5	13660.8	D
100	5	2765	2488.5	27373.5	3987	23386.5	1308
150	5	2450	2205	24255	4730.5	19524.5	D

Adj GY, adjusted grain yield; GB, gross benefit; NB, net benefit; TVC, total variable cost; MRR, marginal rate of return.

interception during photosynthesis thereby contributing to higher biomass accumulation following application of both blended NPSB and FYM [61], which is evidenced by a positive and strong correlation between biomass weight and the number of primary branches per plant ($r = 0.685$) and biomass weight and the leaf area index ($r = 0.407$). In agreement with this finding, different authors reported a significant increase in biomass yield of different legumes as a result of the application of blended NPSB and compost [62], NPK and poultry manure [45]. For instance, Demissie et al. [62] reported that applying 150 kg·ha^{-1} NPSB-blended fertilizer along with compost enhanced barley biomass yield by 11.5 t·ha^{-1}. This could be because sulfur promotes vegetative growth via enhanced chlorophyll production.

3.4.5. Grain Yield. The interaction of NPSB fertilizer rates with FYM had a significant effect on grain yield. Grain yield increased when the rate of both NPSB fertilizer and FYM fertilizer rose from nil to higher levels. The maximum grain yield (2765 kg·ha^{-1}) was achieved with an integrated application of 100 kg NPSB fertilizer·ha^{-1} and 5 t FYM·ha^{-1}, followed by an integrated application of 100 kg NPSB fertilizer·ha^{-1} and 2.5 t FYM·ha^{-1} with a mean grain yield of 2628 kg·ha^{-1} (Table 8). Unfertilized plots produced the lowest grain yield (1013 kg·ha^{-1}), which was 173.3% lower than the best yields. Furthermore, the maximum yield from 100 kg·ha^{-1} NPSB plus 5 t FYM·ha^{-1} was 45.5% and 62% higher, respectively, than the yield from 100 kg·ha^{-1} NPSB alone (i.e., blanket recommendation dose) and 5 t·ha^{-1} FYM. In general, application of 100 kg NPSB·ha^{-1} was found to be superior in grain yield as compared to other rates of NPSB in their respective FYM rates (Table 7).

The increased yield in the integrated application could be due to a synergistic effect of nutrients from mineral fertilizer and macro and micronutrients released from FYM during decomposition, which might have enhanced the photosynthetic activity and protein synthesis in the leaves [55, 61], resulting in improved common bean yield attributes. Pearson correlation analysis also indicated a positive and strong association between grain yield and blended NPSB fertilizer ($r = 0.7016$) and grain yield and FYM ($r = 0.397$) (Table 7). Corroborating the findings of different researchers also evidenced the significant improvement in grain yield of various legumes in response to the integrated application of organic and inorganic nutrients in Ethiopia [11, 15, 46, 63]. For instance, Chala and Obsa [46] reported that chickpea grain yield increased by 246.9% over control in response to the combined application of half the recommended rates of FYM and mineral P. Furthermore, Ndengu et al. [64] observed the highest yields for bush bean intercropped with maize when the combined treatment of manure and fertilizer were applied, followed by the treatment with manure only (Bc).

Furthermore, different authors reported a significant increase in legume grain yield due to the application of blended NPK fertilizer in conjunction with poultry manures or chicken manures on soybean [45] and common bean [58]. For instance, Alhrout et al. [58] reported that the highest grain yield (2710 kg·ha^{-1}) in common bean plants was obtained from plants grown on plots fertilized with mineral NPK and chicken manure.

3.4.6. Harvest Index. The results revealed that the interaction between NPSB and FYM had a substantial impact on the harvest index (HI). The combined application of 100 kg·ha^{-1} NPSB and 2.5 t FYM·ha^{-1} yielded the greatest HI value (53.3%), followed by the same rate of NPSB and 5 t FYM·ha^{-1}that yielded the highest HI value (53.3%) (Table 8). The single application of 5 t FYM·ha^{-1} resulted in the lowest HI value (27.4%). Higher growth and development due to better availability and uptake of macro and micronutrients directly from the applied mineral NPSB and from organic FYM on decomposition resulted in higher biomass accumulation and better partitioning of biomass into yield attributing traits in the later growth stages of the crop, which could explain the increase in HI in response to the integrated application of NPSB and FYM. In agreement, Ghafoor [65] reported a significant increase in the harvest index of faba bean with increase in the rate of N and P fertilizers, which might be due to better biomass accumulation and higher translocation of dry matter and photo-assimilate to the economic part.

3.5. Economic Analysis. The best net benefit (23,386.64 Ethiopian Birr·ha^{-1}) was obtained from the combined application of 100 kg NPSB·ha^{-1} and 5 t FYM·ha^{-1} with an acceptable marginal rate of return (MRR) (1308%), while the lowest net benefit (9367.75 Birr·ha^{-1}) was obtained from the solitary application of 5 t FYM·ha^{-1} (Table 9). Thus, it may be tentatively inferred that combining 100 kg NPSB·ha^{-1}with 2.55 t FYM·ha^{-1}or 5 t FYM·ha^{-1} for increased economic benefits for farmers in the research region is recommended.

4. Conclusion

The study found that combining NPSB fertilizer and FYM had a substantial incremental influence on leaf area index, primary branches, number of nodules, number of pods, hundred seed weight, biomass production, grain yield, and harvest index. The combination of 100 kg NPSB·ha^{-1} and 5 t FYM·ha^{-1} produced the highest seed weight and grain yield. Similarly, raising NPSB fertilizer rates alone from zero to 150 kg NPSB·ha^{-1} resulted in a statistically significant increase in plant height. The use of just FYM from 0 to 5 t·ha^{-1} resulted in a considerable increase in the quantity of seeds per pod. From an economic standpoint, 100 kg of NPSB·ha^{-1} combined with 2.5 t of FYM·ha$^{-1\ \mathrm{or}}$ 5 t of FYM·ha^{-1} is more profitable, with an acceptable marginal rate of return. Thus, for bean growers, a combined application of 100 kg NPSB·ha^{-1} with 2.5 or 5 t FYM·ha^{-1} is recommended.

Data Availability

The data generated by the research are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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