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Research Article

Determination of the Appropriate Blended Inorganic Fertilizer Rate Recommendation for the Optimal Common Bean (*Phaseolus vulgaris* L.) Grain Yield and Profitability in the Dawuro Zone, Ethiopia

Berhanu Bilate Daemo,[1] **Getahun Bore Wolancho**,[1] **and Dawit Dalga Wakalto**[2]

[1]*Department of Plant Science, Wolaita Sodo University, Dawuro Tarcha Campus, P.O. Box 138, Tarcha, Ethiopia*
[2]*College of Agriculture, Wolaita Sodo University, P.O. Box 138, Wolaita Sodo, Ethiopia*

Correspondence should be addressed to Berhanu Bilate Daemo; berhanubil@gmail.com

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Soil fertility decline is a significant factor affecting crop production. In a specific area, fertilizer application for a crop depends on soil type and profitability. Moreover, optimizing chemical fertilizer utilization in crop production is crucial from both environmental and economic perspectives. However, there is limited information available on the optimum NPSB fertilizer rate for common bean production in the study area. Thus, the study aimed to establish area-specific NPSB fertilizer rate recommendations for optimal grain yield and profitability of common bean. The field experiment was conducted in two locations in the 2019 and 2020 cropping seasons. The treatments included 0, 25, 50, 75, 100, 125, 150, 175, and 200 $kg{\cdot}ha^{-1}$ NPSB fertilizer rates, and they were planted using a randomized complete block design with three replications. The combined location analysis of variance indicated that the application of NPSB fertilizer significantly influenced plant height, number of pods per plant, number of seeds per pod, hundred-seed weight, biomass yield, grain yield, and harvest index. The highest grain yields (2815 $kg{\cdot}ha^{-1}$ and 3433 $kg{\cdot}ha^{-1}$) were recorded with the application of a 125 $kg{\cdot}ha^{-1}$ NPSB blended fertilizer rate, while the lowest grain yields (1429 $kg{\cdot}ha^{-1}$ and 1500 $kg{\cdot}ha^{-1}$) were produced from the nonfertilizer applied plot in Deneba and Wara, respectively. The combined location mean showed that the maximum grain yield (3124 $kg{\cdot}ha^{-1}$), followed by 2710 $kg{\cdot}ha^{-1}$, was produced by the application of 125 and 100 $kg{\cdot}ha^{-1}$ NPSB fertilizer rates, respectively. The data indicate that raising the NPSB fertilizer rate from 0 to 125 $kg{\cdot}ha^{-1}$ would greatly boost grain yield in the common bean in both locations in a similar manner. The economic analysis revealed that applying 125 $kg{\cdot}ha^{-1}$ of NPSB fertilizer earned the highest net benefits (140453.2 $ETB{\cdot}ha^{-1}$) with the highest marginal rate of return (1745.26%). Therefore, for high yield and profitability of common bean, a rate of 125 $kg{\cdot}ha^{-1}$ NPSB fertilizer is suggested in the study area and similar agro-ecological zones.

1. Introduction

The common bean, scientifically known as *Phaseolus vulgaris* L., originated in Central and South America and has been cultivated since ancient times, dating back to 6000 BC in Peru and 5000 BC in Mexico [1]. The genus Phaseolus encompasses 80 cultivated and wild species, with the common bean exhibiting significant variation in various traits, such as growth habits, vegetative traits, and pod and seed characteristics [2–4]. Despite the abundance of legume species, the common bean is the most consumed by humans globally. It is estimated to provide over 50% of the dietary protein needs of households in sub-Saharan Africa, yet its positive impact on cropping systems is often overlooked [4, 5]. Common beans are highly valued by low-income individuals who rely on them as a primary source of nutrition due to their affordability compared to meat and fish [3, 6]. Nutritionists highlight their high protein content and rich mix of essential nutrients, including carbohydrates, dietary fiber, iron, and zinc, making them an ideal food source [5, 7]. Over 300 million people worldwide include common beans in their daily diets, reflecting their global popularity [8]. In 2021, common bean production reached 27.5 million metric tons, with Asia accounting for 43% of global production, followed by the Americas at 29% and Africa at 26% [8].

In Ethiopia, common bean cultivation covers approximately 581,041.5 ha of smallholder farmland, yielding 763,740.2 metric tons with an average yield of 1.7 t·ha^{-1} [9]. It serves as a crucial food crop and income source for smallholder farmers [9, 10]. Common bean cultivation is rapidly expanding in Ethiopia, primarily due to its fast maturation, which enables early income generation from both domestic and export markets [11–13]. Despite its versatility, production faces challenges, such as low soil fertility, nutrient imbalances, land degradation, soil acidity, drought, and heat [14, 15]. Many of these challenges can be addressed through breeding and agronomic interventions [15]. Declining soil fertility poses a significant obstacle to common bean production, necessitating an adequate and balanced nutrient supply for optimal yield [14].

Sustaining soil fertility in sub-Saharan Africa, particularly in countries like Ethiopia experiencing rapid population growth, poses a significant challenge. With increasing pressure on agricultural land and the predominance of smallholder farming, ensuring adequate food production has become increasingly difficult [16, 17]. A significant portion of the increase in food production can be attributed to the widespread use of inorganic fertilizers. These fertilizers have demonstrated effectiveness in addressing soil fertility challenges, thereby enhancing crop yields and contributing to food security. Indeed, the efficient utilization of inorganic fertilizers has the potential to greatly enhance soil productivity by transforming unproductive soils into fertile ones [18, 19]. This process not only improves the soil's nutrient content but also promotes better crop growth and higher yields, ultimately contributing to increased agricultural productivity and food security. Inorganic fertilizers, constituting a significant portion of total agricultural production ranging from one-third to one-half, are widely recognized as indispensable inputs in modern agriculture [20]. They play a crucial role in supplementing soil nutrients, optimizing crop growth, and ultimately ensuring sustainable and productive agricultural systems. The utilization of inorganic fertilizers is estimated to contribute significantly to the increase in crop productivity, accounting for approximately 40% to 60% of the observed enhancements [21, 22]. This underscores the pivotal role of inorganic fertilizers in modern agricultural practices and their substantial impact on global food production. Therefore, achieving increased crop yields without a balanced application of fertilizers can result in soil fertility depletion and nutritional imbalances in plants, affecting not only major nutrients but also secondary and micronutrients [14, 23]. This highlights the importance of adopting sustainable fertilization practices that take into account the diverse nutrient needs of crops and the long-term health of agricultural ecosystems. Indeed, integrating the cultivation of improved crop varieties with the judicious application of chemical fertilizers may become imperative for farming operations in developing countries. This approach is essential to maximize crop output and meet the food requirements of families amidst the ongoing challenge of population growth [24, 25].

The soils of Ethiopia exhibit widespread deficiencies in essential nutrients, including nitrogen (86%), phosphorus (99%), sulfur (92%), boron (65%), zinc (53%), and potassium (7%) [26, 27]. The present study's soil analysis results have confirmed that the soils in the study area are deficient in nitrogen, phosphorus, sulfur, and boron fertilizers. This highlights the urgent need for comprehensive soil fertility management strategies to address these deficiencies and sustainably enhance agricultural productivity in the country. As a result, the Ministry of Agriculture Ethiopia has developed a blended multinutrient balanced fertilizer to address site-specific nutrient deficits, thereby enhancing crop production and productivity. A recently introduced blended NPSB fertilizer, with a recommended application rate of 100 kg·ha^{-1}, has been adopted by farmers in the study area. This fertilizer replaces the previously utilized NPS fertilizer, representing a shift toward a more comprehensive nutrient management approach [28, 29]. By incorporating additional nutrients, such as sulfur and boron alongside nitrogen and phosphorus, this blended fertilizer aims to address specific nutrient deficiencies in the soil, thereby supporting improved crop growth and productivity for farmers in the region. Nevertheless, the blanket recommended fertilizer rate of 100 kg·ha^{-1}NPSB was developed elsewhere using other soil types, and it has not yet been proven to be the best dose for common bean production in the research location. Because of this, smallholder farmers and scholars face difficulties in understanding the proper dosages of NPSB fertilizers for common bean production. Furthermore, the application of fertilizers should be tailored to the local climate, soil, and management practices to enhance crop production economically and sustainably [16, 17, 30, 31]. Therefore, comprehension of the plant nutrient needs of a specific area is crucial to increasing crop productivity and production on a sustainable basis. However, there is limited information available on the optimum NPSB fertilizer rate for the production of common bean in the study area. Hence, there is a need to develop area-specific NPSB fertilizer rate recommendations to enhance the productivity and production of common beans. Therefore, the study aimed to determine the optimum NPSB fertilizer rate for the optimal common bean grain yield and profitability.

2. Materials and Methods

2.1. Description of the Study Area. The field experiment was conducted at Deneba and Wara trial sites for two consecutive main cropping seasons under rain-fed conditions during 2019 and 2020. The geographical location of the Deneba trial site lies at 7°21′N and 37°38′E with an altitude of 1150 m above sea level [32]. During the experiment period, the average monthly rainfall in Deneba received 111 mm, with a mean monthly temperature of 26.5°C (Figure 1). The Deneba site has nitosols, which is weathered red soil, and

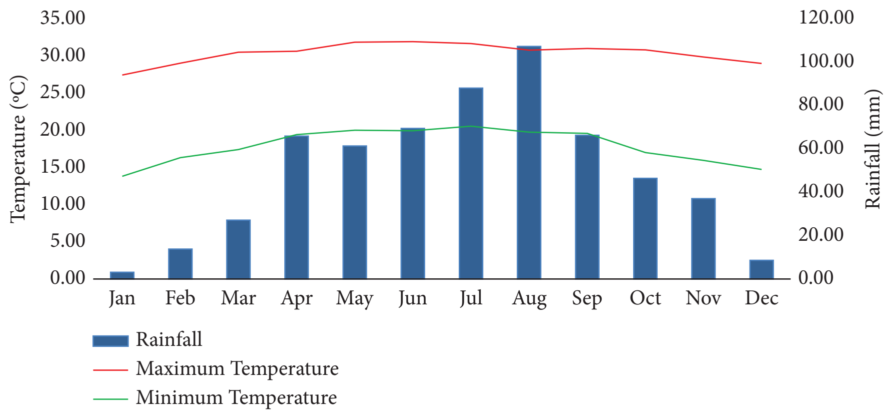

Figure 1: Monthly average rainfall and maximum and minimum temperature data for the Deneba trial site from 2019 to 2020 [34, 35].

a detail description of the physical and chemical characteristics of the soil within the top 30 cm is presented in Table 1. The Wara trial site is located at 7°34′ N and 37°44′ E with an altitude of 1550 m above sea level [32]. During the experiment period, the average monthly rainfall Wara received 138.5 mm with a mean monthly temperature 22.5°C (Figure 2). The Wara location has nitosols and alisols, which is weathered brown soil, and detail description of the physical and chemical characteristics of the soil within the top 30 cm is presented in Table 1.

2.2. Sample Preparation and Soil Analysis. Surface (0–30 cm depth) soil samples were collected from ten randomly selected spots following a "zigzag" pattern across the experimental fields of Deneba and Wara trial sites using an auger and composited into one sample before planting. From this mixture, a 1.0 kg sample was taken, air-dried, ground, and sieved through a 2 mm sieve. Analysis of selected physicochemical properties of soil samples was carried out at the Soil and Water Analysis Laboratory of Horticoop Ethiopia (Horticulture) PLC. The soil analysis was conducted using standard analytical procedures as outlined in Bremner [36], Bouyoucos [37], Chapman [38], and Mehlich [39]. The details of the soil analysis results for the testing site are presented in Table 1.

2.3. Experimental Material, Treatment, Design of Experiment, and Field Management. The non-biofortified common bean variety, named SER-125, served as the test crop. Released by the Melkassa Agricultural Research Center in 2014, SER-125 is well adapted to the study area. The recommended utilization rate for farmers, 100 kg ha^{-1} NPSB (18.9% N, 37.7% P2O5, 6.95% S, and 0.1% B), formed the basis for arranging the treatment. The experiment comprised nine levels of NPSB fertilizer (0, 25, 50, 75,100, 125, 150, 175, and 200 kg·ha^{-1}), with full NPSB applied at planting time according to the prescribed rate per plot. The experiment employed a randomized complete block design with three replications, featuring plot dimensions of 4 meters in width by 3 meters in length, with blocks spaced 1 meter apart. Plots within blocks were spaced 0.5 meters apart. Common bean seeds were sown at a spacing of 0.4 meters between rows and 0.1 meter between plants. The land was plowed three times before planting. Weeding occurred twice (at 21 and 35 days after planting), while pests and diseases were monitored and controlled until harvest. Nitrogen fertilizers release in forms like ammonium (NH_4^+) or nitrate (NO_3^-), prone to leaching, necessitating careful management for optimal plant nutrition and reduced environmental impact. Phosphorus fertilizers gradually release phosphorus ions ($H_2PO_4^-$ and HPO_4^{2-}), requiring proper management practices to maximize utilization efficiency and minimize nutrient losses. Sulfur fertilizers release in the forms of sulfate ions (SO_4^{2-}), dissolving rapidly in soil moisture, offering swift availability to plants, whereas boron fertilizers release, such as borax or boric acid; promptly dissolve in soil moisture; and provide immediate boron supply to plants postapplication. Efficient fertilizer management practices, including timing applications and monitoring soil levels, are crucial for optimizing nutrient utilization, crop productivity, and environmental sustainability.

2.4. Data Collection. Plant height was measured from the central rows in randomly selected 10 plants using a tape measure, and their mean was used for analysis. The number of pods per plant was also counted from these 10 plants, and their mean was computed. The number of seeds per pod was counted from randomly selected 10 plants from the net plot, and the total pod number was divided by the mean for analysis. To estimate aboveground dry biomass yield, 10 plants were tagged during the late pod-forming stage, and old leaves were collected daily and preserved in a polythene bag until crop maturity. The aboveground dry biomass of 10 plants at full physiological maturity from a net plot was measured after seven days of sun drying in the field and converted from kg per plot to kg per hectare for analysis. From the net plot area (9.6 m^2), common bean was harvested, and grain yield (kg per plot) and hundred-seed weight (g) were measured using a sensitive balance. The grain yield was adjusted to 11% standard moisture content and converted from kg per plot to kg per hectare for analysis. Hundred-seed weights (g) were sampled from each experimental unit of cleaned grain seed, counted using an electronic counter, and measured using a sensitive balance after

Table 1: The physical and chemical soil properties of the trial sites.

Parameters	Unit	Deneba Value 2019	Deneba Value 2020	Wara Value 2019	Wara Value 2020	Rating	Reference
Sand	%	36	36	16	16		
Clay	%	28	28	46	46		
Silt	%	36	36	38	38		
Textural class		Clay loam		Silt clay			
pH	—	5.67	5.66	5.47	5.5	Strong acid (5.1–5.5)	[35]
CEC	Cmol(+)/kg soil	24.71	25.1	24.71	23.5	High (15–30)	[35]
P	mg/kg	5.71	6.22	6.75	6.71	Very low (<15)	[35]
S	mg/kg	7.74	7.71	7.83	7.83	Very low(<10)	[35]
B	mg/kg	0.40	0.41	0.49	0.50	Deficiency (<0.5)	[35]
K	mg/kg	358.3	361.2	502.6	503.80	Optimum (190–600)	[35]
Total. *N*	%	0.1	0.11	0.19	0.19	Low (<0.21)	[35]
Ca	mg/kg	1666.3	1666.5	2547.7	2615.1	High (2000–4000)	[35]
Mg	mg/kg	176.3	176.01	286.63	285.12	Moderate (120–360)	[35]

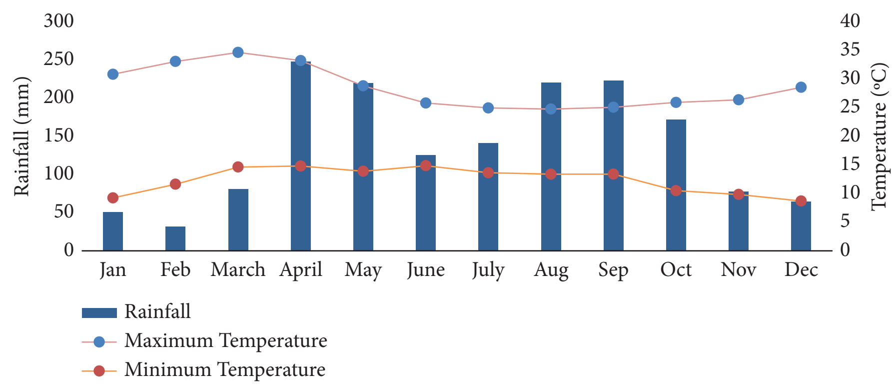

Figure 2: Monthly average rainfall and maximum and minimum temperature data for the Wara trial site from 2019 to 2020 [34, 35].

correcting the seed's moisture content to 11%. Harvest index (%) was calculated using the formula: HI = weight of grain yield/(Weight of aboveground dry biomass yield) ×100.

2.5. Agronomic Data and Economic Analysis. The data analysis of variance was conducted using SAS statistical software, version 9.4 [40]. Treatment mean comparisons were made using the least significant difference (LSD) at a 5% level of significance. Agronomic data from each location and season underwent analysis of variance (ANOVA), and the normality test was conducted using the Shapiro–Wilk W test. Additionally, Bartlett's test was used for assessing the homogeneity of data within each location and season, followed by the combined analysis of variances once homogeneity of error variances was confirmed. The combined analysis of variance (ANOVA) was performed using generalized linear model (GLM) procedures for the randomized complete block design.

$$Y_{\mathrm{ixjk}} = \mu + T_i + S_x + L_j + \mathrm{TS}_{\mathrm{ix}} + \mathrm{TL}_{\mathrm{ij}} + \mathrm{TSL}_{\mathrm{ixj}} + R_k + \varepsilon_{\mathrm{ixjk}}, \tag{1}$$

where Y_{ixjk} is the observed value of treatment i in replication k of season x and location j, μ is the grand mean of the trait, T_i is the effect of treatment i, S_x is the effect of season x, L_j is the effect of location j, $\mathrm{TS}_{\mathrm{ix}}$ is the interaction effect of treatment i with season x, $\mathrm{TL}_{\mathrm{ij}}$ is the interaction effect of treatment i with location j, $\mathrm{TSL}_{\mathrm{ixj}}$ is the interaction effect of treatment i with season x and location j, R_k is the effect of replication k, and $\varepsilon_{\mathrm{ixjk}}$ is the error (residual) effect of treatment i in replication k of season x and location j.

To streamline the statistical analysis of the agronomic data, a partial budget analysis was conducted for each treatment. Economic evaluations included calculations for total variable cost, gross field benefit, net benefit, and marginal rate of return ratios, using the methodology outlined by CIMMYT [41]. Initial estimated costs for analysis comprised the cost of NPSB fertilizer (40.16 ETB kg^{-1}), the cost of NPSB application (500 ETB ha^{-1}), and the current open market price of common bean grain (52.00 ETB kg^{-1}). Following the procedure outlined by CIMMYT [41], farmers were assumed to achieve yields 10% lower than those obtained in the experiment; thus, the mean common bean grain yield was adjusted in the economic analysis by subtracting 10% from the actual yield. The total variable cost (TVC) was determined as the sum of all variable costs, including the cost of chemical fertilizer and labor costs for fertilizer application. The gross field benefit (GFB) was calculated by multiplying the adjusted total grain yield kg ha-1 for each treatment by the current open market price of common bean grain (52.00 ETB kg^{-1}). The net benefit (NB) was obtained as the difference between the GFB and the TVC, and the marginal rate of return (MRR %) was computed (MRR (%) = ΔNB/ ΔTVC × 100) as the change in net benefit over the change in total variable cost between any pair of treatments.

3. Results and Discussion

3.1. Plant Height. The plant height was significantly influenced by the application of different levels of NPSB fertilizer (Table 2) at $p \leq 0.01$. In Deneba, the tallest plant height (80.19 cm) was recorded with the application of 100 kg·ha^{-1} NPSB blended fertilizer rate, while in Wara, the tallest plant height (82.32 cm) was observed with the application of a 125 kg·ha^{-1} NPSB blended fertilizer rate (Table 3). The shortest plant height was observed for the nonfertilizer applied plot in both locations. The pooled location mean performance results showed that the tallest plant height (81.36 cm) was recorded with a 125 kg·ha^{-1} NPSB blended fertilizer rate, followed by 77.69 cm, which was statistically similar with a 100 kg·ha^{-1} NPSB fertilizer rate (Table 3). As the NPSB fertilizer rate increased from 0 to 125 kg·ha^{-1}, the plant height of common beans increased significantly and then declined gradually. This increase in plant height in response to NPSB fertilizer may be attributed to the enhanced availability of N, P, S, and B in the blended NPSB, which promoted vegetative growth and cell division, resulting in enhanced plant height [42]. This study, consistent with Deresa [43] and Taddess et al. [44], reported that inorganic fertilizer application significantly increased common bean plant height up to the maximum NPSB requirement level.

3.2. Number of Pods per Plant and Number of Seeds per Pod. The application of NPSB fertilizer significantly influenced both the number of pods per plant and the number of seeds per pod (Table 2). In Deneba, the highest number of pods per plant (44.33) was observed with a 125 kg·ha^{-1} NPSB fertilizer rate, while in Wara, the maximum number of pods per plant (40.6) occurred with a 100 kg·ha^{-1} NPSB fertilizer rate (Table 4). Across all locations and seasons, the highest mean number of pods per plant (42.46) was achieved with a 125 kg·ha^{-1} NPSB fertilizer rate, followed by 35.5 pods per plant with a 100 kg·ha^{-1} NPSB fertilizer rate (Table 4). The combined location mean results indicated that increasing the NPSB fertilizer rate from 0 to 125 kg·ha^{-1} resulted in an increase in the number of pods per plant, but further increasing the NPSB fertilizer rate from 125 to 200 kg·ha^{-1} maintained a similar number of pods per plant (Table 4). This increase in the number of pods per plant may be attributed to improved nutrient availability in the soil solution due to the optimal application of NPSB fertilizer. Similarly, at Deneba, the highest number of seeds per pod (6.76) was recorded with the application of 100 kg·ha^{-1} NPSB fertilizer rate, followed by 6.0 with the 125 kg·ha^{-1} rate. At Wara, the maximum number of seeds per pod (5.4) was observed with the application of 75 and 125 kg·ha^{-1} NPSB fertilizer rates (Table 4). Combining location means revealed that the highest number of seeds per pod (6.08) was achieved with the 100 kg·ha^{-1} NPSB fertilizer rate, followed closely by 5.66 seeds per pod with the 125 kg·ha^{-1} NPSB fertilizer rate (Table 4). In Deneba, increasing the NPSB fertilizer rate from 0 to 125 kg·ha^{-1}, and in Wara, increasing it from 0 to 175 kg·ha^{-1}, significantly increased the number of seeds per pod, with a subsequent decrease observed after reaching the maximum fertilizer rate. Previous studies by Tadesse et al. [44], Tirfessa et al. [45], and Zewide et al. [46] reported similar findings, where varying NPSB fertilizer rates (100–150 kg·ha^{-1}) resulted in the highest number of pods per plant and seeds per pod. These studies highlight the importance of considering geographical location and soil type when determining optimal fertilizer rates.

3.3. Biomass Yield. The aboveground dry biomass yield was significantly influenced by the application of different levels of NPSB blended fertilizer (Table 2). At Deneba, the highest dry biomass yield (15866 kg·ha^{-1}) was recorded with the application of 150 kg·ha^{-1} NPSB fertilizer rate, followed closely by 15727 kg·ha^{-1}, 15712 kg·ha^{-1}, and 15404 kg·ha^{-1}, which were statistically similar to the application of 200, 175, and 125 kg·ha^{-1} NPSB blended fertilizer rates, respectively. The lowest biomass yield (10157 kg·ha^{-1}) was observed in the nonfertilizer applied plot (Figure 3). Similarly, at Wara, the maximum dry biomass yield (17341 kg·ha^{-1}) was achieved with the application of 150 kg·ha^{-1} NPSB blended fertilizer rate, while the lowest biomass yield (10953 kg·ha^{-1}) was observed in the nonfertilizer applied plot (Figure 3). The pooled location mean showed that the highest biomass yield of 16603 kg·ha^{-1} was obtained with the application of the 150 kg·ha^{-1} NPSB fertilizer rate, followed by 16445 kg·ha^{-1} and 16442 kg·ha^{-1} recorded with the application of 200 and 175 kg·ha^{-1} NPSB blended fertilizer rates, respectively (Figure 3). The findings indicate that an increase in biomass yield was associated with higher NPSB fertilizer rates. The study suggests that blended NPSB rates led to increased biomass yield due to enhanced N availability, plant height, pod number, and vegetative growth. This finding aligns with previous studies by Zewide et al. [46], Mekonnen and Saliha [47], and Dela et al. [48], which reported maximum biomass yields with varying NPSB fertilizer rates.

3.4. Grain Yield. The grain yield of common beans was significantly affected by the application of various levels of NPSB blended fertilizer (Table 2). The highest grain yields (2815 kg·ha^{-1} and 3433 kg·ha^{-1}) were achieved with the application of a 125 kg·ha^{-1} NPSB blended fertilizer rate, while the lowest grain yields (1429 kg·ha^{-1} and 1500 kg·ha^{-1}) were observed in the nonfertilizer applied plots in Deneba and Wara, respectively (Figure 4). In Deneba, the maximum grain yield exceeded that of both the nonfertilizer applied plot and the recommended fertilizer rate plot by 96% and 13.37%, respectively. Similarly, in Wara, the highest grain yield surpassed the nonfertilizer applied plot and recommended fertilizer rate plot grain yield by 128.86% and 16.84%, respectively. The combined location mean performances indicated that the highest grain yield (3124 kg·ha^{-1}),

Table 2: The combined analysis of variance of locations over seasons for growth, yield, and yield-related traits of common bean grown at Deneba and Wara in 2019 and 2020.

Source of variations	DF	Mean squares						
		PH	NPP	NSP	HSW	BY	GY	HI
Treatment (T)	8	3968.2**	366.60**	6.81**	42.89**	72453708.5**	2916793.6**	49.01**
Location (L)	1	219.1NS	1.46NS	11.29**	108.0**	36346502.0**	852242.1**	0.23NS
Year (Y)	1	112.9NS	10.81NS	0.43NS	0.15NS	45007.7NS	643147.1**	60.1*
Replication	2	157.7NS	72.37NS	0.29NS	0.36NS	16690332.5NS	15364NS	11.4NS
T × L	8	772.7NS	54.15*	0.42NS	12.39**	2979786.6NS	178458.9**	15.3NS
T × Y	8	70.6NS	1.87NS	0.15NS	1.92NS	669649.0NS	13845.1NS	3.5NS
T × Y × L	8	61.81NS	0.98NS	0.22NS	1.87NS	131268.0NS	63938.3*	4.8NS
Residual	70	61.59	24.75	0.26NS	3.18	4102878.1	31010.3	9.3

NS, *, ** = nonsignificant at 0.05, significant at 0.05, and highly significant at 0.01 level of probability, respectively; PH = plant height (cm); NPP = number of pods per plant; NSP = number of seeds per pod; HSW = hundred-seed weight (g); BY = aboveground dry biomass yield (kg·ha^{-1}); GY = grain yield (kg·ha^{-1}); HI = harvest index (%).

Table 3: The NPSB blended fertilizer application influenced the plant height (cm) of common beans grown at Deneba and Wara in the 2019 and 2020 cropping seasons.

NPSB rate (kg·ha^{-1})	Plant height (cm)						
	Deneba			Wara			Overall mean
	2019	2020	Mean	2019	2020	Mean	
0	56.6d	62.2d	59.4e	55.06d	61.74f	58.4e	58.9d
25	60.67cd	65.69cd	63.18c–e	75.43ab	70.65de	73.04b–d	68.12c
50	67.5bc	73.28bc	70.39b–d	67.83bc	78.45bc	73.17b–d	71.79bc
75	66.5bcd	67.48b–d	66.99c–e	77.05a	84.38a	80.71ab	73.85bc
100	72.33ab	88.05a	80.19a	76.58ab	82.96ab	79.77a–c	77.69ab
125	78.75a	72.45bc	75.6ab	80.24a	84.40a	82.32a	81.36a
150	67.10b–d	71.68bc	69.39b–d	65.81c	72.61de	69.21d	69.3c
175	71.17a–c	75.63b	73.4a–c	67.2bc	74.59de	70.92cd	72.16bc
200	64.75b–d	73.63bc	69.19b–d	63.46cd	68.63e	66.04de	67.62c
LSD (5%)	10.7	8.2	8.85	9.5	5.4	8.4	6.39
CV	10.1	9.8	9.75	10.86	11.0	9.98	11.02

Means within the same column followed by the same letter or by no letters are not significantly ($p > 0.05$) different.

followed by 2710 kg·ha^{-1} and 2651 kg·ha^{-1}, was obtained with the application of 125, 100, and 150 kg·ha^{-1} NPSB blended fertilizer rates, respectively (Figure 4).

As the NPSB fertilizer rate increased from 0 to 125 kg·ha^{-1}, common bean grain yield increased significantly, but gradually decreased beyond 125 kg·ha^{-1}. The increase in grain yield could be attributed to higher levels of S and B fertilizers, their availability alongside major nutrients, and enhanced crop uptake, influencing crop growth and development of yield components. This influences the growth and development of the yield component of the crop and ultimately leads to the assimilation and partitioning of photosynthates from the source to the sink, resulting in improved chlorophyll absorption and dry-matter production that contribute to the grain yield increase.

On the other hand, the decrease in grain yield associated with NPSB fertilizer rates beyond 125 kg·ha^{-1} may be attributed to an increased nitrogen rate, which promotes excessive vegetative growth in crop plants, consequently reducing the grain yield of common beans. This finding aligns with previous studies by Arega and Mekonnen [42], Deresa [43], Tirfessa et al. [45], Zewide et al. [46], and Dela et al. [48], which suggested that the increase in grain yield with the application of blended inorganic fertilizer could be attributed to the sufficient supply of N, P, S, and B soil solutions for crop uptake. This leads to an increase in the number of branches per plant and, subsequently, an increased photosynthetic area, resulting in more pods per plant and a higher number of seeds per pod. They further noted that the optimal level of blended fertilizer for crops reaches a threshold, beyond which further application would diminish grain yield in common beans.

3.5. Hundred-Seed Weight. The application of NPSB fertilizer significantly influenced the weight of the hundred seeds (Table 2). In Deneba, the highest hundred-seed weight (30.66), followed by 29.0, was recorded with the application of 125 kg·ha^{-1} and 200 kg·ha^{-1} NPSB fertilizer rates, respectively, while the lowest hundred-seed weight (21.7) was observed in the nonfertilizer applied plot (Table 5). Conversely, at Wara, the maximum hundred-seed weight (26.33) was achieved with the application of 100 kg·ha^{-1} NPSB fertilizer rate (Table 5). The combined location mean result showed that the highest hundred-seed weight (27.83) was recorded with the application of 100 kg·ha^{-1} NPSB fertilizer rate (Table 5). As the NPSB fertilizer rates increased from 0 to 200 kg·ha^{-1}, the hundred-seed weight of common beans

Table 4: The NPSB blended fertilizer application influenced the number of pods per plant and number of seeds per pod of common beans grown at Deneba and Wara in the 2019 and 2020 cropping seasons.

NPSB rate ($kg{\cdot}ha^{-1}$)	Number of pods per plant							Number of seeds per pod						
	Deneba			Wara			Overall mean	Deneba			Wara			Overall mean
	2019	2020	Mean	2019	2020	Mean		2019	2020	Mean	2019	2020	Mean	
0	21.67^{c}	22.11^{c}	21.9^{d}	23.32^{d}	23.60^{e}	23.46^{d}	23.46^{d}	3.74^{c}	3.71^{e}	3.73^{e}	3.13^{d}	3.0^{c}	3.07^{d}	3.4^{e}
25	25.65^{bc}	27.45^{bc}	26.6^{cd}	31.17^{b-d}	32.43^{b-d}	31.8^{c}	31.8^{c}	4.87^{bc}	5.09^{d}	4.98^{d}	4.72^{bc}	5.0^{ab}	4.86^{bc}	4.92^{d}
50	28.0^{bc}	27.56^{bc}	27.78^{b-d}	31.83^{a-c}	32.83^{bc}	32.33^{bc}	32.33^{bc}	5.2^{b}	5.24^{cd}	5.22^{cd}	4.43^{c}	5.43^{a}	4.93^{abc}	5.07^{cd}
75	31.33^{b}	32.87^{b}	32.11^{bc}	30.33^{b-d}	32.07^{b-d}	31.2^{c}	31.2^{c}	5.77^{ab}	5.79^{b-d}	5.78^{bc}	5.47^{a}	5.33^{a}	5.4^{a}	5.58^{b}
100	33.0^{b}	33.67^{b}	33.33^{b}	37.33^{ab}	38.0^{ab}	37.66^{ab}	40.6^{a}	6.52^{a}	7.0^{a}	6.76^{a}	5.47^{a}	5.20^{ab}	5.33^{ab}	6.08^{a}
125	43.66^{a}	45.0^{a}	44.33^{a}	40.0^{a}	41.2^{a}	40.6^{a}	37.66^{ab}	5.93^{ab}	6.1^{bc}	6.0^{b}	5.33^{ab}	5.47^{a}	5.4^{a}	5.66^{ab}
150	30.65^{bc}	32.45^{b}	31.55^{bc}	28.67^{cd}	27.85^{c-e}	28.26^{cd}	28.26^{cd}	5.53^{ab}	6.13^{b}	5.83^{bc}	5.20^{ab}	4.8^{ab}	5.0^{abc}	5.41^{bc}
175	31.33^{b}	31.11^{bc}	31.22^{bc}	25.0^{cd}	26.06^{c-e}	25.53^{d}	25.53^{d}	5.33^{b}	5.77^{b-d}	5.55^{b-d}	4.93^{a-c}	5.07^{ab}	5.0^{abc}	5.27^{bcd}
200	30.0^{bc}	29.54^{bc}	29.77^{bc}	26.33^{cd}	24.87^{de}	25.6^{d}	25.6^{d}	5.47^{ab}	5.64^{b-d}	5.55^{b-d}	4.80^{bc}	4.2^{b}	4.5^{c}	5.07^{cd}
LSD (5%)	4.2	4.4	6.14	8.4	7.9	5.38	5.38	1.2	0.8	0.68	0.6	0.9	0.53	0.42
CV	17.9	17.3	16.93	15.9	14.6	14.93	14.93	12.8	8.5	10.53	7.86	10.8	9.37	9.98

Means within the same column followed by the same letter or by no letters are not significantly ($p > 0.05$) different.

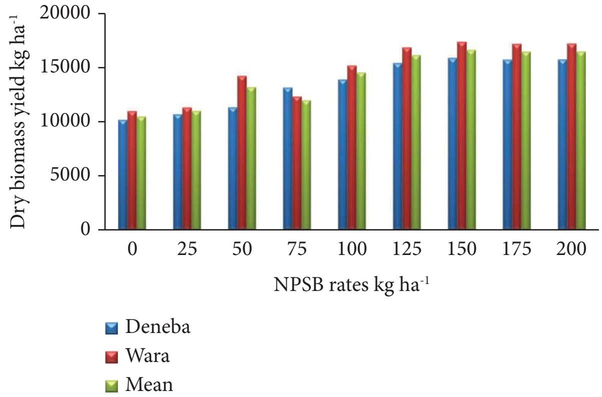

FIGURE 3: The NPSB blended fertilizer application influenced the aboveground dry biomass yield (kg·ha^{-1}) of common beans grown at Deneba and Wara in the 2019 and 2020 cropping seasons.

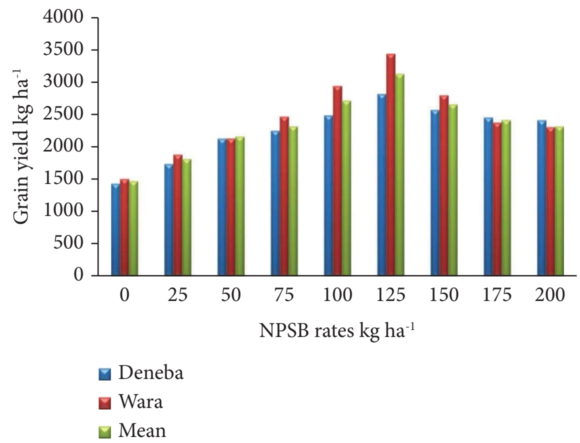

FIGURE 4: The NPSB blended fertilizer application influenced the grain yield (kg·ha^{-1}) of common beans grown at Deneba and Wara in the 2019 and 2020 cropping seasons.

increased (Table 5). Increased hundred-seed weight could be due to improved nutrient use efficiency at optimal levels of N, P, S, and B fertilizer. This result is supported by previous studies by Deresa [43] and Amare et al. [49], which reported a significant increase in seed weight in common beans with the application of blended fertilizer.

3.6. Harvest Index. At Wara, the analysis of variance revealed a significant ($p \leq 0.05$) effect of NPSB application on the harvest index, while at Deneba, the effect was nonsignificant ($p > 0.5$) (Table 2). However, the combined analysis of variance indicated a significant ($p \leq 0.05$) effect of NPSB application on the harvest index (Table 2). The highest harvest index (20.84%) at Wara was achieved with a 75 kg·ha^{-1} NPSB fertilizer rate, followed closely by rates of 125, 100, and 150 kg·ha^{-1}, which showed statistically similar results (Table 5). Across locations, the highest harvest index (19.68%) was observed with the application of 125 kg·ha^{-1} NPSB fertilizer, while the lowest (14.02%) was from the nonfertilizer applied plot (Table 5). Similar to grain yield and aboveground dry biomass yield, increasing the NPSB fertilizer rate from 0 to 125 kg·ha^{-1} was associated with an increase in the harvest index, followed by a decrease beyond that rate (Table 5). This finding aligns with studies by Mekonnen and Saliha [47] and Ejigu and Tulu [50], who reported a significant response of the harvest index in common bean to blended fertilizer application.

3.7. Partial Budget Analysis. The NPSB fertilizer and labor costs, gross incomes, net benefits, and net returns are shown in Table 6. The partial budget analysis was conducted based on the combined location mean performance, determined using the total variable costs and the net benefits of each treatment. In this study, the cost of NPSB fertilizer and labor costs for its application varied, while the other costs remained constant for each treatment. In terms of grain yield and net benefits, the use of NPSB blended fertilizer on common beans outperformed the unfertilized plot. The maximum net benefit was estimated (140453.2 ETB ha^{-1}) for common beans sold with a marginal rate of return (1745.26%) from the application of a 125 kg·ha^{-1} NPSB fertilizer rate. The second-highest net benefit (122128.0 ETB ha^{-1}) with a marginal rate of return (1660.57%) was obtained from the application of a 100 kg ha^{-1} NPSB fertilizer rate (Table 6). Therefore, a 125 kg·ha^{-1} NPSB blended fertilizer rate is a better choice for smallholder farmers to enhance the

Table 5: The NPSB blended fertilizer application influenced the hundred-seed weight (g) and harvest index (%) of common beans grown at Deneba and Wara in the 2019 and 2020 cropping seasons.

NPSB rate ($kg\cdot ha^{-1}$)	Hundred-seed weight (g)							Harvest index (%)						
	Deneba			Wara			Overall mean	Deneba			Wara			Overall mean
	2019	2020	Mean	2019	2020	Mean		2019	2020	Mean	2019	2020	Mean	
0	20.0^{d}	22.0^{d}	21.0^{f}	22.0^{b}	22.66^{b}	22.33^{d}	21.66^{e}	12.86^{b}	15.33	14.09	14.22^{de}	14.08^{bc}	14.15^{c}	14.02^{e}
25	25.33^{c}	23.67^{cd}	24.5^{e}	22.67^{ab}	23.8^{b}	23.23^{cd}	23.91^{d}	16.87^{ab}	16.68	16.77	15.25^{de}	17.99^{a-c}	16.62^{bc}	16.69^{b-d}
50	26.33^{c}	25.33^{b-d}	25.83^{de}	23.67^{ab}	24.33^{ab}	24.0^{b-d}	24.91^{cd}	17.40^{a}	20.71	19.05	13.11^{e}	18.06^{a-c}	15.58^{c}	17.32^{ab}
75	28.0^{a-c}	26.67^{bc}	27.3^{cde}	26.0^{a}	24.67^{ab}	25.3^{a-c}	26.73^{ab}	16.20^{a}	17.48	17.23	19.71^{ab}	21.97^{a}	20.84^{a}	19.01^{ab}
100	28.0^{a-c}	28.0^{ab}	28.0^{bc}	25.33^{a}	27.33^{a}	26.33^{a}	27.83^{a}	17.87^{a}	18.45	18.16	18.16^{bc}	20.54^{ab}	19.34^{ab}	18.76^{ab}
125	30.0^{c}	31.33^{a}	30.66^{a}	25.33^{a}	24.65^{ab}	25.0^{abc}	26.66^{ab}	17.07^{a}	20.4	18.73	20.71^{a}	20.53^{ab}	20.62^{a}	19.68^{a}
150	27.33^{bc}	26.67^{bc}	27.0^{cde}	26.0^{a}	25.33^{ab}	25.66^{ab}	26.33^{bc}	15.51^{ab}	16.14	15.82	16.35^{cd}	16.29^{a-c}	16.32^{ab}	16.07^{c-e}
175	26.33^{bc}	27.0^{bc}	26.66^{cd}	25.0^{ab}	25.67^{ab}	25.33^{a-c}	26.0^{bc}	15.38^{ab}	15.80	15.59	13.7^{e}	14.41^{bc}	14.04^{c}	14.83^{de}
200	29.33^{ab}	28.67^{ab}	29.0^{ab}	25.0^{ab}	24.33^{ab}	24.66^{a-c}	26.83^{ab}	14.42^{ab}	18.24	16.33	13.75^{e}	13.11^{c}	13.43^{c}	14.88^{c-e}
LSD (5%)	2.2	3.7	2.0	3.1	3.5	2.2	1.5	4.1	6.6	3.5	2.5	6.9	3.4	2.5
CV	5.2	8.0	6.6	7.2	8.1	7.5	7.1	14.8	16.3	15.6	9.1	13.5	11.5	13.6

Means within the same column followed by the same letter or by no letters are not significantly ($p > 0.05$) different.

Table 6: Economic analysis of grain yield influenced by NPSB fertilizer rates.

NPSB ($kg\cdot ha^{-1}$)	UGY ($kg\cdot ha^{-1}$)	AGY ($kg\cdot ha^{-1}$)	Fertilizer cost ($ETB\cdot ha^{-1}$)	Fert. app. cost ($ETB\cdot ha^{-1}$)	TVC ($ETB\cdot ha^{-1}$)	GFB ($ETB\cdot ha^{-1}$)	NB ($ETB\cdot ha^{-1}$)	MRR
0	1466	1319.4	0	0	0	68608.8	68608.8	
25	1811	1629.9	1050.0	500.0	1550.0	84754.8	83204.8	941.68
50	2155	1939.5	2100.0	500.0	2600.0	100854.0	98254.0	1433.0
75	2315	2083.5	3150.0	500.0	3650.0	108342.0	104692.0	613.14
100	2710	2439.0	4200.0	500.0	4700.0	126828.0	122128.0	1660.57
125	3124	2811.6	5250.0	500.0	5750.0	146203.2	140453.2	1745.26
150	2651	2385.9	6300.0	500.0	6800.0	124066.8	117266.8	D
175	2411	2169.9	7350.0	500.0	7850.0	112834.8	104984.8	D
200	2314	2082.6	8400.0	500.0	8900.0	108295.2	99395.2	D

1US Dollar = 55 ETB current exchanging rate. UGY = unadjusted grain yield $kg\cdot ha^{-1}$, AGY = 10% adjusted gain yield $kg\cdot ha^{-1}$, TVC = total variables costs (ETB), GFB = gross field benefit (ETB), NB = net benefit (ETB), MRR = marginal rate of return (%), and D = dominated.

productivity and production of common beans in the study area and similar soil types.

4. Conclusion

Since fertilizer application depends on the soil fertility status in a particular agro-ecological zone, information regarding the optimum rate of NPSB fertilizer in a specific area for common bean production is crucial for smallholder farmers. The study conducted various levels of NPSB fertilizer in two locations over two consecutive seasons to determine the optimum rate for common bean production. The results reveal that the application of NPSB fertilizer significantly influences plant height, number of pods per plant, number of seeds per pod, hundred-seed weight, biomass yield, and grain yield. The findings showed that 125 $kg\cdot ha^{-1}$ NPSB was the best rate for common bean production, which produced the highest mean grain yield and the highest net benefits (140453.2 ETB ha^{-1}) with the highest marginal rate of return (1745.26%). Therefore, common bean-growing farmers should use the 125 $kg\cdot ha^{-1}$ NPSB fertilizer rate in the study area and in similar agro-ecological zones and soil types.

4.1. Future Research Perspectives. Previous studies on pulse crops, including common beans, have highlighted the significant yield increase and soil quality improvement resulting from combining chemical fertilizer with Rhizobium strains. Therefore, future research should focus on exploring the potential benefits of blended fertilizers in conjunction with inoculating common beans with suitable Rhizobium species.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Berhanu Bilate Daemo conceptualized the study, contributed to data curation, performed formal analysis, provided funding acquisition, performed investigation, proposed the methodology, provided project administration, wrote the original draft, and reviewed and edited the article. The remaining authors performed the field work and contributed to the writing of the manuscript. The final manuscript has been read and approved by all authors for submission.

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