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Common Bean (*Phaseolus vulgaris* L.) Yield Response to Coffee Husk Biochar and NPSB Fertilizer in Southwest Ethiopia

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Abstract

Common bean (*Phaseolus vulgaris* L.) is an economically important pulse crop in Ethiopia, yet its productivity remains low due to soil acidity and poor nutrient management. A field experiment was conducted during the 2025 cropping season at Kayikela and Kicho Districts, Southwest Ethiopia, to evaluate the optimum combination of coffee husk biochar and NPSB blended fertilizer for maximizing yield and economic return. Treatments consisted of four CHB levels (0, 2.5, 5, and 7.5 t ha⁻¹) and four NPSB rates (0, 50, 100, and 150 kg ha⁻¹) arranged in a factorial randomized complete block design with three replications. Data were analyzed using SAS 9.4, and treatment means were separated using LSD at 5%. Results revealed that combined CHB and NPSB applications significantly ($p < 0.01$) affected most growth, phenology, and yield traits, except days to emergence and stand count. The highest mean values for days to flowering (50 and 48), days to maturity (91 and 89), branch number (7.9 and 6.3), plant height (44.2 and 38.3 cm), and pod length (41.3 and 33.6 cm) were recorded under 7.5 t ha⁻¹ BC with 150 kg ha⁻¹ NPSB at Kayikela and Kicho, respectively. Similarly, maximum pods per plant (35 and 26), seeds per pod (5.1 and 5), hundred seed weight (41 and 36 g), aboveground biomass (5724.6 and 5308.3 kg ha⁻¹), harvest index (43 and 52), and seed yield (2483.6 and 2373.3 kg ha⁻¹) were obtained from 5 t ha⁻¹ BC combined with 150 kg ha⁻¹ NPSB. This treatment also provided the highest net benefit (101,437 ETB ha⁻¹ at Kayikela and 95,989 ETB ha⁻¹ at Kicho). Therefore, application of 5 t ha⁻¹ BC with 150 kg ha⁻¹ NPSB can be tentatively recommended for enhancing common bean productivity in the study areas.

Keywords: *Blended fertilizer, Coffee husk biochar, Common bean, Yield*

1. INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is an important grain legume of the Fabaceae family and a major source of dietary protein, minerals, vitamins, and other essential nutrients for millions of people worldwide. The crop was domesticated in the Mesoamerican and Andean regions and is now widely cultivated across tropical and subtropical environments, particularly by smallholder farmers in Africa, Latin America, and Asia (Gepts & Debouck, 1991; Berny, 2020; Cassino et al., 2021). In Ethiopia, common bean is among the major pulse crops and plays an important role in food and nutritional security, household income, and soil fertility management through biological nitrogen fixation. However, its productivity remains substantially below its attainable potential. The low productivity is associated with several interacting constraints, including limited access to improved and locally adapted varieties, inadequate agronomic practices, declining soil fertility, and poorly optimized fertilizer management (Tadesse et al., 2022; Alemayehu et al., 2025; Jaleta et al., 2025).

Declining soil fertility is one of the major constraints to sustainable common bean production in Ethiopia (Zewudie et al., 2019). Long-term cultivation, nutrient removal through crop harvest, soil erosion, and unbalanced fertilizer use have progressively depleted soil nutrient reserves. Although mineral fertilizers have historically been used to address widespread nitrogen (N) and phosphorus (P) deficiencies, their continued application without adequate consideration of other essential nutrients has contributed to nutrient imbalance and declining fertilizer-use efficiency (IFPRI, 2010; Elias et al., 2019). Soil fertility assessments have further demonstrated deficiencies of potassium (K), sulfur (S), zinc (Zn), boron (B), and copper (Cu), in addition to N and P, across major Ethiopian soils, emphasizing the need for balanced and site-specific nutrient management (Zewide et al., 2016). Consequently, fertilizer recommendations based solely on blanket applications of conventional N and P fertilizers may be inadequate for sustaining crop productivity under heterogeneous soil conditions.

The challenge is particularly pronounced in high-rainfall areas, where nutrient leaching can further reduce the availability of mobile nutrients and accelerate soil fertility decline. Continuous reliance on mineral fertilizers, together with inadequate organic matter replenishment, may also adversely affect soil chemical, physical, and biological properties over the long term (Tadesse et al., 2018; Mengesha et al., 2022). Therefore, sustainable intensification of common bean production requires nutrient management strategies that simultaneously address immediate crop

nutrient requirements and the long-term maintenance of soil health. Integrated use of organic amendments and balanced mineral fertilizers provides a promising approach because organic inputs can improve soil organic matter, water retention, nutrient buffering, and biological activity, while mineral fertilizers provide readily available nutrients required for rapid crop growth and yield formation (Zewide et al., 2012; Wato et al., 2024).

Among organic soil amendments, biochar has received increasing attention because of its distinctive physicochemical properties and potential to improve both soil quality and nutrient-use efficiency. Biochar is a carbon-rich, porous material produced through the thermochemical conversion of biomass under oxygen-limited conditions and contains varying proportions of carbon, hydrogen, oxygen, nitrogen, sulfur, and mineral ash (Sri Shalini et al., 2021; Gupta et al., 2022). Its relatively stable carbon fraction allows biochar to persist in soil for extended periods, while its porous structure and surface functional groups can enhance nutrient retention, water-holding capacity, and soil structural stability (Gupta et al., 2020). These effects can be particularly important in acidic and highly weathered tropical soils, where nutrient fixation, leaching, and low soil organic matter constrain crop productivity (Wu et al., 2021). Thus, biochar may complement mineral fertilizers by improving the soil environment in which nutrient uptake occurs rather than serving simply as an additional nutrient source.

The potential of biochar is particularly relevant in Southwest Ethiopia, where coffee production and processing generate substantial quantities of coffee husk. Converting this locally abundant agricultural residue into biochar offers a potential circular nutrient-management strategy by transforming an underutilized biomass resource into a soil amendment. However, the agronomic value of biochar depends on its interaction with fertilizer type, application rate, soil properties, crop nutrient requirements, and prevailing environmental conditions. Therefore, although biochar can improve nutrient retention and availability, its effects vary considerably with biochar characteristics, application rate, soil properties, and environmental conditions, and it may not consistently supply sufficient readily available nutrients to meet crop requirements (Bekchanova et al., 2024). Integrating biochar with balanced mineral fertilizers may therefore provide a more effective nutrient-management strategy by combining the nutrient-retention and soil-conditioning functions of biochar with the readily available nutrients supplied by mineral fertilizers. Such complementary nutrient management can enhance nutrient availability and use efficiency and ultimately improve crop growth and productivity (Wabela et al., 2024).

In the Kaffa zone, common bean production has traditionally relied largely on blanket fertilizer recommendations, with farmers commonly applying conventional fertilizer rates without adequately accounting for spatial variability in soil fertility, soil acidity, crop-specific nutrient requirements, or the contribution of locally available organic resources. This limitation is particularly important in high-rainfall environments, where nutrient losses and soil acidity can constrain fertilizer-use efficiency. At the same time, the widespread availability of coffee husk presents an opportunity to develop locally appropriate soil fertility management practices. Despite this potential, there is limited site-specific information on the agronomic response of common bean to the combined application of coffee husk-derived biochar and balanced blended fertilizers in the acidic soils of Southwest Ethiopia.

The novelty of this study lies in integrating a locally available coffee-processing residue, converted into biochar, with blended NPSB fertilizer as a site-specific nutrient-management strategy for common bean production under the soil and climatic conditions of Southwest Ethiopia. Rather than evaluating organic amendment or mineral fertilizer as isolated inputs, the study examines their combined effects, thereby addressing both short-term nutrient supply and longer-term soil fertility improvement. This approach is particularly relevant for acidic, high-rainfall production environments where nutrient losses, soil fertility decline, and inefficient use of conventional fertilizers constrain productivity. The study therefore provides an opportunity to identify an agronomically effective and locally adaptable combination of coffee husk biochar and NPSB fertilizer that can improve common bean productivity while contributing to more sustainable use of agricultural residues and mineral nutrients. Accordingly, the present study was conducted to evaluate the effects of different rates of coffee husk biochar and blended NPSB fertilizer, individually and in combination, on the growth, yield components, and grain yield of common bean in Southwest Ethiopia. The study further seeks to identify an appropriate integrated nutrient-management option that can enhance fertilizer-use efficiency, utilize locally available coffee-processing residues, and contribute to sustainable common bean production under the prevailing soil and climatic conditions.

2. Materials and Methods

2.1. Description of the Study Areas

The field experiment was conducted at two locations, specifically Kayikela and Kicho kebeles, in Bonga town and Gimbo district, respectively, in the Kaffa zone, Southwest Ethiopia, during the 2025 cropping season. The two locations represent two different growing agro-ecologies and soil textural classes (Figure 1). Kayikela kebele is found 9 km from the center of Bonga town and 437 km from Addis Ababa. Geographically, it is located at an altitude of 1780 m.a.s.l. with a latitude of 07°19'449" N and a longitude of 36°13'446" E. The area received 1700 mm annual rainfall, and the average temperatures increase from 5.4 - 23.7°C. The soil type is Nitisol with the textural class of sandy loam, whereas Kicho kebele is found in Gimbo district, which is 18 km away from Bonga town and 428 km from Addis Ababa, and is located at 07°24'19.3" N and 36°14'11.1" E. It receives 1680 mm of annual rainfall, and the average temperatures increase from 6.4–25.7°C. The altitude of the area is 1720 m.a.s.l. with average temperatures increasing from 13.1 - 26 °c. The soil type is Nitisol with the textural class of sandy soil.

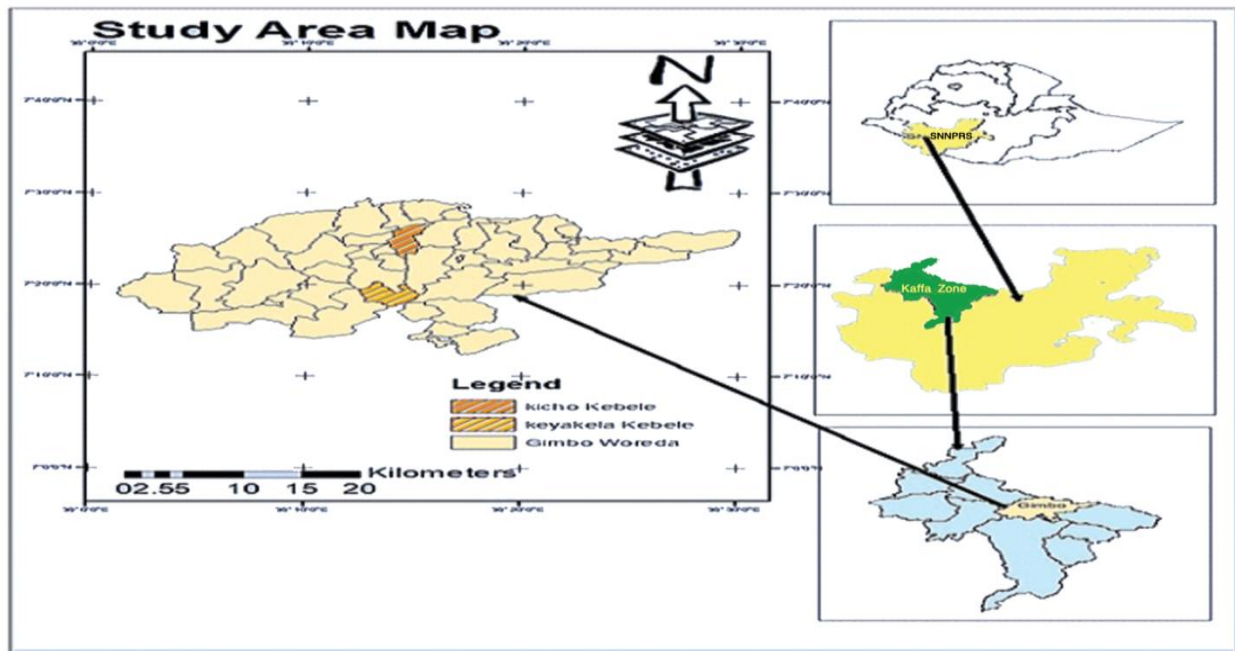


Figure 1:- Map of the study areas. **Source:** UTM ZONE 37N – WGS-84 (Pragada & Rajan 2025).

2.2. Experimental Material

The common bean variety, SAB 736 (Ado), was used for the study. It is preferred by experimental site farmers for its early maturity (82-93 days) as a catch crop during the food gap, and it has a large size, oval and white seed with a white flower color, and a bushy growth habit. Yield of this variety on the farmer's field and research field is 1800-2200 kg ha⁻¹ and 2000-2500 kg ha⁻¹, respectively. It is ecologically adapted to the areas, because the growing areas are within an altitude of 1450-2000 m.a.s.l., annual rainfall 1142-1450 mm, and planting date ranges from mid-June to July. Common bean seed was obtained from Bonga Agricultural Research Center (BARC) in the 2022 growing season, which was released by Melkasa Agricultural Research Centre in 2015 (MoA, 2016).

2.3. Soil and Biochar Sampling and Analysis Procedure

Pre-planting soil samples from the experimental sites were collected from 9 spots in a zigzag pattern at a depth of 0-30 cm. Composited and one kg samples were taken to the laboratory. The samples were air dried, powdered using a pestle and mortar, and allowed to pass through a 2-mm sieve in Jimma Agricultural Research Center's Soil and Plant Tissue Culture Laboratory. Soil samples were tested for soil texture, soil pH, organic carbon, total N₂, available phosphorus, and cation exchange capacity (CEC) using standard laboratory procedures. Organic carbon content was determined by the volumetric method (Walkley & Black, 1934). N₂ content of the soil was analyzed by the Kjeldahl digestion, distillation, and titration procedure (Brummer & Mulyaner, 1982). The cation exchange capacity (CEC) was measured after saturating the soil with 1N ammonium acetate (NH₄OAc) and displacing it with 1N NaOAc (Chapman, 1965). Available phosphorus was determined by Olsen's method using a spectrophotometer (Olsen et al., 1954). Soil pH was measured in water at a soil-to-water ratio of 1:2.5 (Van, 1992). Soil textural analysis was performed by the Bouyoucos hydrometer method (Day, 1965). Detailed compositions were tabulated here under Table 1.

Table 1. Pre-physicochemical properties of the soils

Soil Characteristics	Fertility status of the soil before sowing					
	Locations				Methods	References
	Keyikela		Kicho			
Soil texture size distribution	values	Rating	values	Rating		
Physical analysis						
Clay %	23.2		20			EthioSIS (2016)
Silt %	29.3		22.1		Hydrometer method	
Sand %	47.5		57.9			
Textural classes	Sandy Loam at Kayikela and Sandy soil at Kicho, respectively.					
Chemical analysis						
pH (1: 2.5)	5.4	Moderately acidic	5.16	Moderately acidic	Water (H ₂ O) at 1:2.5 soils	EthioSIS (2016)
					Carbon is oxidized under standard conditions.	
TN. (%)	0.24	Medium	0.22	Medium	Oxidizing the organic matter with sulfuric acid	EthioSIS (2016)
A.P (mg kg ⁻¹)	7.52	High	5.4	High	Bray 2 method	EthioSIS (2016)
CEC (cmole(+) ₋₁ kg	27.3	Medium	26.1	Medium	Ammonium acetate method	EthioSIS (2016)

Where: A.P (mgkg⁻¹); available phosphorus, CEC (cmole (+)kg⁻¹); cation exchange capacity, OC (%); organic carbon, TN (%); total nitrogen.

The biochar produced from coffee husk contains a high percentage of fixed carbon (>60 wt%), suggesting that biochar produced from coffee husk is suitable for carbon sequestration and also contributes a high level of soil organic matter. It was determined that the mass fraction of carbon in the biochar could be correlated to the mass fraction of volatile matter (VM), fixed carbon (FC), and ash (ASH) by the relationship $C = 0.474 \cdot VM + 0.963 \cdot FC + 0.067 \cdot ASH$ (www. Scirp.org> paper info.com). According to Pearl et al. (2015), the skin of the coffee fruit horn contains 1.27 % nitrogen (N), 0.06 % phosphorus (P), and 2.46 % potassium (K). The use of coffee bean husks as a raw material in composting will provide multiple benefits. Results of the coffee husk biochar analysis indicated that it had relatively high contents of phosphorus and total carbon, and the pH was alkaline. Detailed compositions of the coffee husk biochar are tabulated here under Table 2.

Biochar was characterized for pH, EC, CEC, total C, total N, Available P, and ash content. Biochar pH and Electrical conductivity (EC) were measured in distilled water at a 1:10 biochar-to-water mass ratio after shaking for 30 min (ASTM Standard, 2009). Available phosphorus (P) was determined by using the Olsen extraction method (Shaheen et al., 2009). Soil and biochar cation exchange capacity was determined at soil pH 7 after displacement by using the 1N ammonium acetate method and then estimated titrimetrically by distillation of ammonium that was displaced by sodium (Venkatesh, 2022). The ash content of the biochar was also determined in dry ash procedures using a high-temperature muffle furnace capable of maintaining temperatures between 500 and 600 °C.

Table 2. Physicochemical properties of the coffee husk biochar

Parameters	Values	Amount of CHB applied to both sites in (ton)
pH (1:2.5)	8.03	
C (g kg ⁻¹)	403.9	
N (g kg ⁻¹)	19	0.2
K (cmol (+) kg ⁻¹)	23.2	
Carbon /Nitrogen (C: N)	18:1	
P (ppm)	2871	
CEC (cmol (+) kg ⁻¹)	41	

Where: CEC; cation exchange capacity, p; phosphorus, N; nitrogen, K; potassium, C: N, ratio of carbon to nitrogen

2.4. Treatments and the Experimental Design

The treatments over location consisted of four levels of biochar (0, 2.5, 5, and 7.5 t ha⁻¹) and four levels of NPSB (0, 50, 100, and 150 kg ha⁻¹ NPSB blended fertilizer). Phosphorus rates were calculated based on the blanket recommendation of P₂O₅ for common beans on Nitisol, which is 100 kg ha⁻¹. Treatments were arranged in a factorial combination using a randomized complete block design (RCBD) with three replications (Table 3).

Table 3. Descriptions of Experimental Treatments

Trt	Descriptions		Treatment Combinations
	NPSB (kg ha ⁻¹)	BC (t ha ⁻¹)	
T1	0	0	F ₁ BC ₁ 0 kg ha ⁻¹ and BC 0 t ha ⁻¹
T2		2.5	F ₁ BC ₂ 0 kg ha ⁻¹ and BC 2.5 t ha ⁻¹
T3		5	F ₁ BC ₃ 0 kg ha ⁻¹ and BC 5 t ha ⁻¹
T4		7.5	F ₁ BC ₄ 0 kg ha ⁻¹ and BC 7.5 t ha ⁻¹
T5	50	0	F ₂ BC ₁ 0 kg ha ⁻¹ and BC 0 t ha ⁻¹
T6		2.5	F ₂ BC ₂ 0 kg ha ⁻¹ and BC 2.5 t ha ⁻¹
T7		5	F ₂ BC ₃ 0 kg ha ⁻¹ and BC 5 t ha ⁻¹
T8		7.5	F ₂ BC ₄ 0 kg ha ⁻¹ and BC 7.5 t ha ⁻¹
T9	100	0	F ₃ BC ₁ 0 kg ha ⁻¹ and BC 0 t ha ⁻¹
T10		2.5	F ₃ BC ₂ 0 kg ha ⁻¹ and BC 2.5 t ha ⁻¹
T11		5	F ₃ BC ₃ 0 kg ha ⁻¹ and BC 5 t ha ⁻¹
T12		7.5	F ₃ BC ₄ 0 kg ha ⁻¹ and BC 7.5 t ha ⁻¹
T13	150	0	F ₄ BC ₁ 0 kg ha ⁻¹ and BC 0 t ha ⁻¹
T14		2.5	F ₄ BC ₂ 0 kg ha ⁻¹ and BC 2.5 t ha ⁻¹
T15		5	F ₄ BC ₃ 0 kg ha ⁻¹ and BC 5 t ha ⁻¹
T16		7.5	F ₄ BC ₄ 0 kg ha ⁻¹ and BC 7.5 t ha ⁻¹

Where, F₁: fertilizer rate 0; F₂: fertilizer rate 50; F₃: fertilizer rate 100; F₄: fertilizer rate 150; BC₁: biochar rate 0; BC₂: biochar rate 2.5; BC₃: biochar rate 5; BC₄: biochar rate 7.5.

2.5. Experimental Procedures and plot management

The experimental field was plowed by oxen, disked, and harrowed before sowing. The gross plot size of 1.3 m x 3.6 m = 4.68 m², and the net plot size was 1.2m x 3.2m (3.84 m²), which contained 9 rows per plot and 12 plants per row. The common bean seed was sown in the inter-row spacing of 40 cm and intra-row spacing of 10 cm as recommended by Merga (2020).

Biochar could be obtained by subjecting the biomass to pyrolysis. Pyrolysis is a process of combusting biomass under limited oxygen levels (Mona et al., 2021). Coffee husk was collected into a heap and heated to temperatures of 350 °C for a time of 48 hrs as recommended by (Periyasamy et al., 2022). Application of experimental treatments, where the prepared and

degraded coffee husk biochar (as an organic source) was applied a month before the sowing date for better incorporation with soil, and NPSB blended fertilizer was used (as an inorganic source) and applied in the band at sowing time, based on the specific rates required. The seed was sown on July 26, 2022. The spacing between blocks and plots was 1 m x 0.5 m, respectively. Weeding and other crop management practices, such as pest and disease control, were done for all experimental plots as required. The outermost row on each side of a plot was left as a border row, and the middle seven rows were used for data collection and yield measurement.

2.6. Data Collection and Measurement

2.6.1. Crop phenological and vegetative growth parameters

Days to Emergence (days): This was determined by counting the number of seedlings from planting to the time when 50 % of them emerged in a plot.

Days to flowering (days): This was determined by counting the number of days from planting to the time when the first flowers appeared in 50 % of the plants in a plot.

Days to physiological maturity (days): It was determined as the number of days from planting to the time when 90 % of the plants started senescence of leaves (yellowing of the foliage), and pods started to turn yellow.

Number of branches per plant (N_b): It was determined by counting the total number of branches on randomly pre-tagged ten plants in the net plot at physiological maturity and averaged on a per-plant basis.

Plant height (cm): It was measured at physiological maturity from the base to the tip of a plant for randomly pre-tagged ten plants in harvestable rows using a tape meter and averaged on a plant basis.

2.6.2. Nodulation parameter

A total number of nodules (N_n): Nodulation was assessed at the 50 % flowering stage (mid-flowering stage) of the plants. Ten randomly selected plants from destructive rows were carefully uprooted for the determination of nodulation by exposing roots with the bulk of root mass and nodules. Soil adhering to the roots was removed by gently washing with tap water. Nodules from the crown and lateral roots were removed separately and spread on a sieve for some minutes until

the water was drained from the surface of the nodules. The total number of nodules was counted, and the average number of nodules per plant was calculated.

2.6.3. Yield components and yield

Crop stand count (N_0): The plants from the net plot area were counted at crop harvest without uprooting to find the plant population per hectare.

Number of pods per plant (N_0): It was recorded based on ten pre-tagged plants in each net plot area at harvest, and the average was taken as the number of pods per plant.

The number of seeds per pod (N_0): The total number of seeds in the pods of the ten plants was counted and divided by the total number of pods to find the number of seeds per pod.

Hundred seed weight (g): It was determined for each plot using a sensitive balance. The weight was adjusted to a moisture content of 10 %.

Grain yield (kg ha^{-1}): It was measured by harvesting the crop from the net plot area. The moisture was adjusted to 10% by using a grain moisture tester.

Above-ground dry biomass yield (kg ha^{-1}): At physiological maturity, ten plants randomly taken from the destructive rows of each plot were used to determine above-ground dry biomass yield, which was measured after sun drying. The dry biomass per plant was then multiplied by the total number of plants per net plot and was converted into kg ha^{-1} . This value was used to calculate the harvest index as well.

Harvest Index (HI): Harvest index was calculated by dividing grain yield per plot by the total above-ground dry biomass yield per plot, as recommended by Donald *et al.* (1976).

$$\text{HI (\%)} = \frac{GY}{AGBY} * 100 \dots \dots \dots 1$$

2.7. Data Analysis

Collected data were subjected to the analysis of variance (ANOVA) using the statistical software program of SAS version 9.4 (2019). Mean separation was carried out to determine significant differences among treatment combinations using the Least Significant Difference (LSD) test at 5% probability level, and the Coefficient of Variance (C.V.) was calculated to reveal the relative measure of variation that exists within the data. Data from both locations were analyzed separately on a location basis after testing for ANOVA assumptions such as normality and homogeneity (*i.e.*, the data were normal, and at the time heterogeneous over locations).

3. Results and Discussions

3.1. Soil and Biochar Physico-chemical Properties of the Experimental Sites

The laboratory test results for soil in the experimental sites were mainly occupied by sand fraction, as it contained 47.5 and 57.9 % sand, 29.3 and 22.1 % silt, and 23.2 and 20 % clay, and texturally classified as sandy loam in Keyikela and sandy soil in Kicho locations, respectively (Table 1).

The experimental site soil reactions were moderately acidic conditions with a pH of 5.4 in Kayikela and 5.16 in Kicho, respectively. According to Tekalign (1991), who reported that soils having pH values in the range of 5.3-5.9 are moderately acidic. In the same way, Graham & Ranalli (1997) reported that in soils with a pH lower than 5, survival of *Rhizobium* becomes critical. This indicates that the pH of the experimental soils was more or less within the range of optimum for common beans.

The test revealed that the available P_2O_5 of the soil was 2.4 and 2.16 $mg\ kg^{-1}$ at Kayikela and Kicho, respectively (Table 1). Indicative ranges of available phosphorus have been established by Olsen *et al.* (1954), as $<5\ mg\ kg^{-1}$ (very low), 5-15 $mg\ kg^{-1}$ (low), 15-25 $mg\ kg^{-1}$ (medium), and $>25\ mg\ kg^{-1}$ of soil (high). Thus, the soils of the experimental sites were considered very low in available P_2O_5 content, which is unsatisfactory for optimum common bean growth and yield. The low available P_2O_5 could be due to fixation in such acidic soils with Aluminum (Al) and Iron (Fe) oxides. Thus, it is important to apply biochar first to solve the fixation problem and then phosphorus fertilizer from external sources based on the recommended rate.

Tekalign (1991) has classified soil total N content of $<0.05\ %$ as very low, 0.05-0.12 % as poor, 0.12-0.25 % as moderate, and $>0.25\ %$ as high. According to this classification, the soil samples were found to have a moderate level of total N_2 (0.24 in Kayikela and Kicho 0.22 % respectively, Table 1), indicating that the nutrient is a limiting factor for optimum crop growth. Thus, the level of N_2 in the soil showed the need to apply starter N_2 (with in NPSB) for legumes until they start to fix atmospheric N_2 . This result is in agreement with this: Zewide *et al.* (2012) reported that incorporation of starter N_2 together with P_2O_5 , regardless of the N_2 content in the soil, therefore, stimulates growth and enhances efficient nodulation and assimilation of N_2 by faba bean (Alemu & Wato, 2023). Similarly, Singh *et al.* (2023) also indicated that N_2 is required as a starter fertilizer at the early growth stage since there is no nodule formation where atmospheric N_2 is fixed.

The soil of the study sites had 2.49 % in Kayikela and 2.27 % in Kicho of organic carbon (OC) (Table 1), which are moderate according to the rating of Tekalign (1991), which rated soils having OC value in the range of 0.5-1.5 % as low, indicating the low potential of the soil to supply nitrogen to plants through mineralization of organic carbon. The moderate amount of OC might be due to the addition of biochar, good aeration due to reduction in soil compaction of sub-soils, and medium activity of both zymogenous and autochthonous microorganisms that play a great role in organic material decomposition (De la Rosa et al., 2022). Thus, regular application of organic manure, such as crop residues and farm yard manure, is required for the study area.

Cation exchange capacity (CEC) is an important parameter of soil because it indicates the type of clay mineral present in the soil and its capacity to retain nutrients against leaching. According to Landon (1991), top soils having CEC greater than 40 cmol (+) kg⁻¹ are rated as very high and 25-40 cmol (+) kg⁻¹ as high, and 15-25, 5-15, and <5 cmol (+) kg⁻¹ of soil are classified as medium, low, and very low, respectively, in CEC. According to this classification, the soil of the experimental sites had medium/moderate CEC (30 cmol (+) kg⁻¹ soil in Kayikela and 26.5 cmol (+) kg⁻¹ soil in Kicho), respectively. These indicate their medium capacity to retain cations (Table 1). This medium CEC may be attributed to the low percentage of clay (23.2% in Kayikela and 20% in Kicho, respectively) and a high percentage of sand (47.5% in Kayikela and 57.9 % in Kicho, respectively), and also the acidic nature of the soil.

The biochar produced from coffee husk contains high percentages of fixed carbon (>60 wt%), suggesting that biochar produced from coffee husk is suitable for carbon sequestration and also contributes a high level of soil organic matter ([www. Scirp org> paper info.com](http://www.scirp.org/paper/info.com)). The weight (W1-W2) was determined to determine the sample's percentage moisture content, on fixed carbon content, and as temperature rises, so does the amount of fixed carbon (Tesfaye et al., 2022). According to Gottstein et al. (2021), the skin of the coffee fruit horn contains 1.27 % nitrogen (N), 0.06 % phosphorus (P), and 2.46 % potassium (K). The use of coffee bean husks as a raw material in composting will provide multiple benefits. Results of the coffee husk biochar analysis indicated that it had relatively high contents of phosphorus and total carbon, and the pH was alkaline.

3.2. Growth and Phenological Parameters of Common Bean

3.2.1. Days to flowering (days)

The analysis of variance indicated that days to 50 % flowering were highly significantly ($p<0.01$) influenced by the combined effects of BC and P rates. The highest number of days required for flowering (53.3 days in Kayikela and 55.6 days in Kicho) was recorded for the highest rates of BC (7.5 t ha^{-1}) and NPSB blended fertilizer (150 kg ha^{-1}) (Table 4), while the shortest days to 50 % flowering (44.3 and 43 days) were recorded in the control plots of Kayikela and Kicho, respectively (Table 4).

The probable reason for the prolonged days to flowering might be the highest rate of nutrients applied besides sources, especially in the Kayikela location, which is comparatively fertile soil (surrounded by forest), than the Kicho location (continuously cultivated land), promoting vegetative growth rather than a reproductive phase. The result obtained from the current study revealed that the days to flowering were delayed with the increment of the application rate of BC and NPSB blended fertilizer, which could be due to the delaying effect of nitrogen obtained from BC and NPSB blended fertilizer. The current finding for the shortest day of maturity for this cultivar is in agreement with the finding of Loha et al. (2023), who reported that the shortest day to flowering (44.40) was observed for variety SAB 736. Likewise, the result of the longest day taken for 50 % flowering was in line with Reta (2015), who reported that increasing the nitrogen rate from nil to 69 kg N ha^{-1} significantly prolonged the days to 50 % flowering of linseed. This might be because an excessive supply of N_2 promotes luxuriant and succulent vegetative growth, dominating the reproductive phase.

3.2.2. Days to physiological maturity (days)

The combined application of BC and NPSB rates over location had a significant ($p<0.01$) effect on days to 90 % physiological maturity. A shorter number of days (82.6 days and 84.6 days) was recorded for the control plots, which were fertilized with 0 rates of BC and NPSB ha^{-1} , while the treatments that received 7.5 t BC with $150 \text{ kg NPSB ha}^{-1}$ took a longer number of days (90.5 and 91.3 days) to physiological maturity at Kicho and Kayikela locations, respectively (Table 4).

The observed increase in days to maturity relative to the control could be attributed to the higher levels of NPSB blended fertilizer combined with biochar, which may have prolonged crop maturity by enhancing vegetative growth through the nitrogen component of the fertilizer. Furthermore, days to physiological maturity were slightly extended at Kayikela compared to Kicho. This difference may be explained by the environmental conditions at Kayikela, which are

surrounded by dense biomass that likely enhanced nutrient recycling in addition to the applied treatments. This result is consistent with the findings of Singh (1981), who reported that the physiological maturity of common bean is influenced by growth habit and location. Conversely, Alemu et al. (2018) noted that P_2O_5 application can shorten the time to physiological maturity by regulating key enzyme reactions involved in accelerating crop development. Similarly, the present result contradicts the findings of Nebret (2012), who observed a non-significant interaction between nitrogen and sulfur on days to flowering of common bean. It also differs from Tigist et al. (2020), who attributed variation in days to maturity (76–106 days) primarily to mismatches between variety and environmental conditions.

3.2.3. Number of branches per plant (No)

The number of common bean branches was highly significantly ($p < 0.001$) affected by the combined application of BC and NPSB blended fertilizer in the Kayikela location and significantly ($p < 0.05$) influenced in the Kicho location. The highest number of branches (7.9 in Kayikela and 6.3 in Kicho) was observed at the highest rates of NPSB blended fertilizer and BC application (150 kg and 7.5 t ha⁻¹), while the lowest number of branches (2.4 in Kayikela and 2.1 in Kicho) was recorded in the control plots (Table 4). Application of BC and NPSB showed (69.6 and 66.6 %) increments in the number of branches from the rate of 150 kg NPSB and 7.5 t BC ha⁻¹, respectively, as compared to control plots.

The positive growth response of common bean to soil-applied biochar (BC) may be attributed to the creation of a more favorable environment that enhances phosphorus (P) availability as the rate of P_2O_5 application increases. The observed increase in the number of branches with higher P application rates could be linked to the role of BC in improving P availability, thereby enhancing the physiological effect of P in actively growing tissues, particularly at shoot tips, where metabolic activity is high. Adequate P supply promotes bud initiation and cell division, which in turn contributes to increased branching (Table 4). This finding agrees with Mohammed & Feleke (2022), who reported that the number of primary branches increased in acidic soils with higher P application. Conversely, the lowest number of branches per plant in this study may be explained by reduced nutrient availability and the inherent soil acidity of the experimental site.

3.2.4. Plant height (cm)

The analysis of variance showed that the plant height was highly significantly ($p < 0.001$) influenced by the combined application of BC and NPSB blended fertilizer at both Kayikela and Kicho locations. The highest plant height (46.5 cm in Kayikela and 41.3 cm in Kicho locations) was recorded from a combined application of 7.5 t ha⁻¹ BC with 150 kg ha⁻¹ NPSB blended fertilizer in both locations, which is statistically similar to the plant height (44.2 cm) was obtained from the mixed application of 5 t ha⁻¹ BC with 150 kg ha⁻¹ NPSB blended fertilizer in Kayikela location (Table 4). The lowest plant height (24.9 cm in Kayikela and 22 cm in the Kicho location) was obtained from control treatments, which are statistically par with plant height (20.1 cm), recorded from the sole application of 2.5 t ha⁻¹ BC in the Kayikela location (Table 4).

The maximum plant height of common bean observed under higher rates of biochar (BC) and NPSB blended fertilizer application can be attributed to the increased nitrogen availability resulting from their combined use. This enhanced nutrient supply creates a favorable environment for vegetative growth and promotes active cell division, ultimately leading to greater plant height. This finding is consistent with Situmeang et al. (2023), who reported that compost application had no significant effect on plant height, whereas biochar showed a highly significant effect. Similarly, Torres et al. (2023) demonstrated that the tallest common bean plants were obtained with increasing biochar concentrations, which was associated with improved nutrient uptake as nutrient availability increased linearly with higher biochar doses.

3.2.5. Number of Nodules per Plant (N_0)

Nodule numbers were significantly ($p < 0.01$) influenced by location due to the interaction effects of BC and P₂O₅ application. A common bean variety produced significantly different nodule numbers across the rate levels of NPSB blended fertilizer and BC. The highest nodule numbers per plant (41.3 and 38) from the treatments that received 150 kg NPSB and 7.5 t BC ha⁻¹ at Kayikela and Kicho locations, respectively, over the control (Table 4).

The greater number of nodules observed at the highest rates of biochar (BC) combined with NPSB blended fertilizer suggests that BC contributed to soil pH improvement, while phosphorus (P) played a critical role in nodule development through its fundamental functions in plant metabolism as an energy source. Phosphorus is essential for enhancing shoot and root growth, accelerating the activation of nodules, and improving their effectiveness in supporting the host legume. Moreover, the application of P₂O₅ following soil amendment with biochar was found to

increase both the number and size of nodules (Zewdie & Hassen, 2021). This finding is consistent with earlier reports by Mesfin (2014) and Zewdie & Hassen (2021), who demonstrated significant positive effects of P₂O₅ on nodule formation in common bean.

Table 4. Growth and phenological traits as affected by biochar and NPSB rates applied at Kayikela and Kicho in 2025.

Treatments		DF (days)		DPM (days)		NB (No)		PH (cm)		NNP (No)	
NPSB (kg ha ⁻¹)	BC (t ha ⁻¹)	Locations									
		Kayikela	Kicho	Kayikela	Kicho	Kayikela	Kicho	Kayikela	Kicho	Kayikela	Kicho
0	0	44.3 ^g	44 ^h	84.6 ^h	82.6 ^g	2.4 ⁱ	2.1 ^h	24.9 ⁱ	22 ^g	20 ^j	20.9 ^f
	2.5	45.0 ^{hg}	45.0 ^{hg}	85.3 ^{hg}	83.3 ^{hg}	2.6 ^h	2.3 ^g	25.1 ⁱ	24.4 ^{egf}	22.1 ^h	22.3 ^{fe}
	5	45.0 ^{hg}	45.6 ^g	86.0 ^g	84 ^g	2.8 ^{gh}	2.4 ^{fg}	26.0 ^{hi}	25.6 ^{edf}	22.3 ^h	22.8 ^{fe}
	7.5	46.6 ^{de}	46.6 ^f	86.0 ^g	85 ^f	3.0 ^{gf}	2.6 ^e	27.2 ^{ghi}	26.6 ^{ed}	23 ^g	24.6 ^{de}
50	0	44.3 ^g	44 ^h	84.6 ^h	82.6 ^h	2.4 ⁱ	2.1 ^h	28.2 ^{ghf}	23.1 ^{gf}	20 ^j	20.7 ^f
	2.5	46.6 ^{de}	46.6 ^f	87.3 ^f	85 ^f	2.8 ^{gh}	2.4 ^{fg}	29.2 ^{gfe}	24.1 ^{egf}	21.3 ⁱ	22.1 ^{fe}
	5	47.6 ^{dc}	47.6 ^e	88.3 ^e	86 ^e	3.1 ^f	2.5 ^{fg}	30.6 ^{dfe}	26.3 ^{ed}	24.2 ^f	20.6 ^f
	7.5	48.6 ^c	48.6 ^{dc}	89.3 ^d	87 ^{dc}	3.3 ^e	3.2 ^d	33.1 ^{dc}	31.6 ^c	27.6 ^e	27.6 ^c
100	0	44.6 ^{fg}	44.6 ^h	85.0 ^h	83.3 ^{hg}	2.3 ⁱ	2.3 ^g	28.2 ^{ghf}	24.1 ^{egf}	21 ⁱ	20.6 ^f
	2.5	48.3 ^c	48.3 ^{de}	88.3 ^e	86.6 ^{de}	3.1 ^f	2.4 ^{fg}	31.5 ^{dce}	28 ^d	22.9 ^g	22.1 ^{fe}
	5	50.0 ^b	49.3 ^{bc}	89.6 ^{dc}	87.6 ^c	5.1 ^d	3.2 ^d	34.1 ^c	33 ^c	23.9 ^f	27.1 ^{dc}
	7.5	50.0 ^b	50.0 ^{ba}	90.6 ^{ba}	88.6 ^b	6.3 ^b	5.3 ^c	39.1 ^b	40 ^{ba}	35.3 ^b	35.0 ^b
150	0	44 ⁱ	44 ^h	85.0 ^h	83.3 ^{hg}	2.4 ⁱ	2.2 ^g	28.8 ^{ghfe}	24.6 ^{egf}	20.1 ^j	20.4 ^f
	2.5	48.6 ^c	48.6 ^{dc}	89.3 ^d	87.6 ^b	3.4 ^e	3.3 ^d	37.7 ^b	31.2 ^c	28.3 ^d	25.9 ^{dc}
	5	50.6 ^b	49.6 ^b	90.3 ^{bc}	87.6 ^b	5.7 ^b	5.5 ^b	44.2 ^a	38.3 ^b	34.6 ^c	33.6 ^c
	7.5	50.6 ^b	50.6 ^a	90.3 ^{bc}	90.5 ^a	7.9 ^a	6.3 ^a	46.5 ^a	41.3 ^a	41.3 ^a	38 ^a
LSD		1.16 ¹	0.97	0.938	0.669	0.215	0.151	2.918	2.939	0.584	2.88
CV	(%)	4.4	3.9	5.9	3.4	3.8	6.7	6	4.2	5.4	3.3

Where: DF: days to 50 % flowering, DPM: days to 90 % physiological maturity, NB: number of branches, PH: plant height, NNP: number of nodules per plant, LSD: least significance difference, CV: coefficient of variance.

3.3. Yield components and yield

3.3.1. Number of pods per plant (No)

The productive potential of the common bean is ultimately determined by the number of pods per plant, which is the main yield component. The number of pods per plant was significantly ($p < 0.01$)

influenced by the interaction effects of biochar and NPSB blended fertilizer rate. The results showed that the highest number of pods per plant (34 and 22.6 no) was recorded from the treatments that received 5 t BC and 150 kg NPSB ha⁻¹, whereas the lowest number of pods per plant (8.1 and 8 no) was recorded from the control plots at Kayikela and Kicho locations, respectively (Table 5).

This is due to the biochar likely improving soil structure, water-holding capacity, and cation exchange capacity, thereby enhancing nutrient retention and availability to the crop. In addition, biochar helps ameliorate soil acidity, creating a more favorable root environment for nutrient uptake. Also, the application of NPSB blended fertilizer supplied essential macronutrients (N and P) required for vigorous vegetative growth and reproductive development, as well as secondary and micronutrients (S and B) that play critical roles in protein synthesis, nodule functioning, and pod formation. Together, these amendments enhanced photosynthetic activity and assimilate partitioning toward reproductive organs, resulting in a greater number of pods per plant. In contrast, the control plots received no external nutrient inputs, and the inherently acidic and nutrient-depleted soils of the sites limited nutrient uptake, root development, and overall plant vigor. This restriction of growth and assimilate production resulted in the lowest number of pods per plant at both locations. The current finding was in line with different authors, who reported that significant variations in the number of pods per plant on different crops, including common bean, due to P₂O₅ applications (Mesfin et al., 2014; Tesfaye et al., 2015; Dejene et al., 2021). Additionally, Shanka et al. (2015) reported that the Red-Wolaita variety produced the highest number of pods per plant in response to the application of 92 kg P₂O₅ ha⁻¹, which was in statistical parity with the number of pods produced by Red Wolaita and Nasir at the rates of 69 kg P₂O₅ ha⁻¹ and Hawassa-Dumeat at 69 and 92 kg P₂O₅ ha⁻¹ at Kokate.

3.3.2. Pod length (cm)

Analysis of variance showed significant ($p < 0.01$) variations in pod length due to the interaction effect of BC and NPSB blended fertilizer rates. The results showed that the treatments with 5 t BC and 150 kg NPSB ha⁻¹ produced the longest pod length (11.8 and 11 cm) whereas the shortest pod length (8.6 cm and 8.5 cm) was recorded from the control treatments at Kayikela and Kicho, which are statistically similar with pod length (8.6 cm) was obtained from mixed application of 50 kg NPSB and 0 t BC ha⁻¹ and (8.6 cm) was obtained from mixed application of 0 kg NPSB and 2.5 t

ha⁻¹ and 46 kg NPSB and 0 t BC ha⁻¹ in Kayikela and Kicho locations respectively (Table 5). Longer pod formation due to the application of BC followed by NPSB blended fertilizer might be attributed to improvement in growth traits owing to improved availability of P₂O₅, which could play an important role in cell division. Similarly, Abdulkedir (2022) reported that the observed yield improvement might be attributed to an increase in the availability of essential nutrients in the soil. Thus, the enhanced nutrient supply promoted vigorous vegetative growth, which subsequently improved the photosynthetic capacity of the plants. As a result, more photoassimilates were produced and efficiently translocated to the developing pods, thereby contributing to higher pod filling and ultimately greater yield.

3.3.3. Number of seeds per pod (N₀)

Analysis of variance showed that the number of seeds per pod was highly significantly ($p < 0.001$) influenced by the main and interaction effects of BC and P fertilizer rate. The results revealed that the treatments with 5 t ha⁻¹ BC and 150 kg ha⁻¹ NPSB blended fertilizer were applied and recorded the highest seeds per pod (5.1 in Kayikela and 5 Kicho) locations, and which were statistically similar with seeds per pod of (5 and 4.5) obtained from combined application of 7.5 t ha⁻¹ BC with 100 kg ha⁻¹ NPSB blended fertilizer in both location respectively, whereas the lowest number of seeds per pod (2.9 in Kayikela and 3 in Kicho) were recorded from the control plots at both locations, which are statistically similar with number of seeds per pod 2.9 (0 kg ha⁻¹ and 0 t ha⁻¹) and 3 (0 kg ha⁻¹ and 2.5 t ha⁻¹, 50 kg ha⁻¹ and 0 t ha⁻¹, 100 kg ha⁻¹ and 0 t ha⁻¹ and 150 kg ha⁻¹ and 0 t ha⁻¹) were obtained from mixed application of above listed tons ha⁻¹ BC with kg ha⁻¹ NPSB blended fertilizer respectively (Table 5).

The improvement in crop growth and yield could be explained by the combined application of biochar (BC) and NPSB fertilizer to soils that are inherently low in available phosphorus (P₂O₅) and have become nutrient-depleted over years of cultivation. The NPSB fertilizer directly supplied essential macronutrients (N and P) and secondary/micronutrients (S and B), thereby alleviating the immediate nutrient limitations for plant growth. Meanwhile, the biochar enhanced soil properties by reducing acidity, improving nutrient retention, and increasing the efficiency of applied fertilizers. This synergistic effect not only improved root growth and nutrient uptake but also ensured a sustained supply of nutrients throughout the growing period, ultimately leading to better crop growth and higher yields. Similarly, Tunebo et al. (2020), the possible reason for the increase

in crop growth and yield might be attributed to the fact that applying both BC and NPSB fertilizers to soils that are naturally low in available P_2O_5 , and in soils that have been exhausted. This finding was supported by Silva et al. (2017) and Torres et al. (2023), who reported that the greatest growth and productivity of crops in soils fertilized with biochar are due to the improvements of the soil chemical, physical, and biological properties. In addition to being a source of nutrients, biochar can raise soil pH, contributing to the decrease of soil acidity and aluminum toxicity and increase of CEC and nutrient availability, mainly phosphorus, which has strong interactions in acidic soils (Dai et al., 2017; Zhang et al., 2025).

Table 5. Yield component and yield parameters as affected by biochar and NPSB rates applied at Kayikela and Kicho in 2025.

Treatment		NPP (N <u>o</u>)		PL (cm)		NSP (N <u>o</u>)	
		Locations					
NPSB (kg ha ⁻¹)	BC (tha ⁻¹)	Keyikela	Kicho	Keyikela	Kicho	Keyikela	Kicho
0	0	8.1 ^j	8 ^h	8.6 ^e	8.5 ^h	2.9 ^g	3.0 ^g
	2.5	8.2 ^j	8 ^h	8.7 ^{de}	8.6 ^h	3 ^g	3.0 ^g
	5	8.3 ^j	8.1 ^h	8.9 ^{de}	8.7 ^{hg}	3.03 ^{fg}	3.0 ^g
	7.5	8.4 ^j	8.26 ^{gh}	9.1 ^{dce}	8.9 ^{hfge}	3.13 ^{fg}	3.1 ^{gf}
50	0	8.1 ^j	8.2 ^h	8.6 ^e	8.6 ^{hg}	3 ^g	3.0 ^g
	2.5	12.0 ^h	8.9 ^{gfh}	8.9 ^{de}	8.8 ^{hfg}	3.1 ^{efg}	3.1 ^{gf}
	5	14.0 ^g	10 ^f	9.3 ^{dc}	9.1 ^{dfge}	3.2 ^{df}	3.2 ^{ef}
	7.5	16.0 ^{fe}	12 ^e	9.6 ^c	9.4 ^{dc}	3.3 ^{ed}	3.3 ^{ed}
100	0	10.1 ⁱ	8.1 ^h	8.8 ^{de}	8.6 ^h	3 ^g	3.0 ^g
	2.5	15.0 ^{fg}	12 ^e	8.8 ^{de}	9.2 ^{dfce}	3.3 ^{ed}	3.3 ^{ed}
	5	22.0 ^d	12 ^e	9.6 ^c	9.6 ^c	4.1 ^{bc}	3.9 ^c
	7.5	31.0 ^b	16 ^c	10.5 ^c	10.5 ^b	5.0 ^a	4.5 ^a
150	0	12 ^h	9.5 ^{gf}	8.8 ^{d^e}	9 ^{hg}	3 ^g	3 ^g
	2.5	25.0 ^c	19 ^b	10.6 ^b	10.6 ^b	3.5 ^d	4.0 ^b
	5	34.0 ^a	22.6 ^a	11.8 ^a	11 ^a	5.1 ^a	5.0 ^a
	7.5	17.0 ^e	15 ^{dc}	10.5 ^c	9.4 ^{dce}	3.5 ^d	3.4 ^d
LSD		1.533	1.278	0.583	0.477	0.205	0.140
CV (%)		6.5	5.9	4.6	4	5.3	3.5

Where: NPP: Number of pods per plant, PL: Pod length, NSP: Number of seeds per Pod, LSD: least significant difference, CV: coefficient of variance.

3.3.4. Above-ground dry biomass yield (kg ha⁻¹)

The above-ground dry biomass yield of the common bean cultivar was highly significantly ($p < 0.001$) influenced by the combined application of BC and NPSB blended fertilizer over the

location. The mean above-ground dry biomass yield of the common bean cultivar varied across different rates of BC and P_2O_5 . The maximum above-ground dry biomass yield was recorded (5724.6 and 5308.3 kg ha⁻¹) from plots that received 5 t ha⁻¹ BC and 150 kg NPSB ha⁻¹, while the minimum biomass (4188.6 and 3959.6 kg ha⁻¹) was from control plots of Kayikela and Kicho, respectively. But the dry biomass produced 4193 kg ha⁻¹ and 4189 kg ha⁻¹ (0 kg NPSB with 2.5 t BC and 150 kg ha⁻¹ NPSB with 0 t BC ha⁻¹, respectively) that grew at both the highest and lowest P (control) were statistically similar (Table 6).

The possible reason for the variation in dry biomass yield of the cultivar across the 5 t ha⁻¹ biochar and 150 kg ha⁻¹ NPSB levels might be attributed to BC that reclaimed the pH condition of the soil and thereby enhanced the availability of P_2O_5 for root growth and several nodules, which increases nutrient absorption that contributes to the full development of above-ground parts of the plants. This finding is in agreement with other authors, Elka, & Laekemariam et al. (2020), who reported that interactive effects of NPS and Organic Fertilizer significantly influenced the biomass yield of haricot beans. Similarly, Torres et al. (2023) reported that the higher biomass production with biochar application shows it is possible to produce leguminous plants, similar to the common bean, to be used as green fertilizers, for example, in the recovery of degraded areas.

3.3.5. Hundred Seed weight (g)

The analysis of variance showed that the hundred seed weight was significantly ($p < 0.01$) influenced by the combined application of coffee husk biochar and NPSB blended fertilizer rates. The result showed that the highest hundred seed weights (40 g in Kayikela and 35 g in Kicho) were produced from the plots that received 5 t ha⁻¹ BC and 150 kg ha⁻¹ NPSB blended fertilizer rate at both locations, whereas the lowest hundred seed weights (27 g in Kayikela and 25 g in Kicho, respectively) were obtained from control plots. Hundred seed weight (32.6 g) at the Kicho location was recorded from the treatments that received (2.5 t ha⁻¹ BC with 150 kg ha⁻¹ NPSB and 7.5 t ha⁻¹ BC with 150 kg ha⁻¹ NPSB) were statistically similar (Table 6). Hundred-seed weight is also an important yield component that reflects the magnitude of seed development, which ultimately reflects on the final yield of a crop.

The possible reason for these results might be the suitable soil environment, especially at the Kayikela growing location, due to the positive influence of microclimate factors, besides coffee husk biochar. The results were in agreement with Zafar et al. (2013), who reported that the increase

in hundred-seed weight as a result of increased P application might be attributed to the important roles that P_2O_5 played in the regenerative growth of the crop, leading to increased seed size, which in turn may improve hundred-seed weight. In the same way, Beebe et al. (2014) and Dereje et al. (2016) described that the observed significant variations in the hundred seed weights of common bean cultivars as a result of P application. Thus, the application of P_2O_5 might improve the seed quality of beans.

3.3.6. Seed yield ($kg\ ha^{-1}$)

The seed yield of common bean over location was significantly ($p < 0.001$) affected by the combined effect of coffee husk biochar and NPSB fertilizer rates. The results showed that the highest seed yield ($2483.6\ kg\ ha^{-1}$ in Kayikela and $2373.3\ kg\ ha^{-1}$ in Kicho) was produced from the treatment that received $5\ t\ ha^{-1}$ BC and $150\ kg\ ha^{-1}$ NPSB blended fertilizer at both locations, whereas the lowest seed yields ($1411\ kg\ ha^{-1}$ in Kayikela and $1298\ kg\ ha^{-1}$ in Kicho) were recorded from control plots (Table 6). However, the national average yield of common bean was $1600\ kg\ ha^{-1}$, the yield potential of variety SAB-736 (Ado) on the research field was $2000\text{--}2500\ kg\ ha^{-1}$ (Abate et al., 2018). Therefore, the current result was more or less the nearest to the yield potential of the variety due to soil fertility management via application of BC and NPSB blended fertilizer rates.

The possible reason for the increase in seed yield might be attributed to the overall improvement in growth aspects such as the number of branches and aboveground dry biomass yield, thereby increasing yield promoting traits such as the number of pods per plant, number of seed per pod and hundred seed weight upon partitioning, which also showed an increasing trend as a result of combined application of BC and NPSB blended fertilizer rates. The outcomes of these studies were in agreement with other authors, Gobeze & Legese (2015), who observed significant variations in seed yield for different crops, including common bean. It is also consistent with Loha et al. (2023), who reported significant increases in the seed yields of common beans in response to P_2O_5 application under field and greenhouse conditions. In contrast, Tolera et al. (2005) reported a non-significant effect of P application on seed yield of climbing bean intercropped with maize at Bako, Western Oromia region of Ethiopia, on acid soil. The lowest seed yield at the control plots could be explained by the fact that essential plant nutrients are deficient, which can limit plant growth, flower number, pod setting, and development. The present

result is in line with Beebe et al. (2014), who described that seed yield decreased without the application of P₂O₅ fertilizer.

3.3.7. Harvest index (%)

The combined effects of BC and NPSB blended fertilizer had a significant ($p < 0.01$) influence on the harvest index. The combined mean comparison showed that the highest harvest index (53.2 % in Kicho and 43.3 % in Kayikela) was recorded at the treatments that received 5 t BC ha⁻¹ and 150 kg ha⁻¹ NPSB blended fertilizer at both locations, respectively. Whereas the lowest value was received from control plots (Table 6). The highest combined mean of harvest index indicates biological success in partitioning assimilated photosynthates to the harvestable product (Li et al., 2003). This finding is in agreement with Wasonga et al. (2008), who reported a significant increase in the harvest index of soybean due to P₂O₅ fertilizer application.

Generally, this experiment showed that the combined application of 7.5 t ha⁻¹ BC and 150 kg ha⁻¹ NPSB was not directly proportional to the increment of the yield parameters of the cultivar, as in 5t ha⁻¹ BC and 150kg ha⁻¹ NPSB blended fertilizer rates. This might be due to the optimum nutrient requirement of the test crop in those locations were restricted to 5t ha⁻¹ BC and 150 kg ha⁻¹ NPSB blended fertilizer rates, and no additional yield increment was recorded as the level of treatments increased. Whereas, the combined application of 7.5 t ha⁻¹ biochar along with 150 kg ha⁻¹ was directly proportional to the increments of yield component parameters of the test crop in both locations. The possible reasons for this could be that the nitrogen content of the soil in both locations was at its optimum range, as indicated by soil laboratory test results before sowing, in addition to the application of nitrogen from external sources through BC and NPSB blended fertilizer rates, which might boost the yield component parameters at the expense of yield parameters.

Table 4. Yield component and yield parameters as affected by biochar and NPSB rates applied at Kayikela and Kicho in 2025.

Treatments		ADB (kg ha ⁻¹)		HSW (g)		SY (kg ha ⁻¹)		HI (%)	
		Locations							
NPSB (kg ha ⁻¹)	BC (tha ⁻¹)	Keyikela	Kicho	Keyikela	Kicho	Keyikela	Kicho	Keyikela	Kicho
0	0	4188.6 ^k	3959.6 ^l	27.0 ^m	25.0 ^k	1411.0 ^l	1301.3 ⁿ	33.6 ^k	43.7 ^{ji}

	2.5	4193.0 ^k	4023.0 ^j	28.0 ^l	26.0 ^{ik}	1417.6 ^k	1368.6 ^k	33.8 ^j	44.1 ^{hji}
	5	4220.6 ^j	4100.6 ⁱ	29.0 ^k	27.0 ^{ji}	1446.0 ^j	1407.0 ^j	34.2 ⁱ	44.4 ^{hgi}
	7.5	4224.0 ^{ji}	4119. ^h	30.0 ^j	28.0 ^{hi}	1449.0 ^j	1422.3 ⁱ	34.3 ^{ih}	45.8 ^{fe}
50	0	4187.3 ^k	3993. ^k	29.0 ^l	25.6 ^k	1414.3 ^{lk}	1302.0 ⁿ	33.7 ^{kj}	43.6 ^j
	2.5	4235.6 ⁱ	4035.0 ^j	29.0 ^l	29.0 ^{hg}	1456.0 ⁱ	1371.0 ^k	34.3 ^h	46.0 ^e
	5	4624.0 ^h	4223. ^g	32.0 ^h	30.0 ^{fg}	1618.0 ^h	1493.6 ^h	34.9 ^g	45.1 ^{fg}
	7.5	4883.6 ^f	4529.3 ^e	33.0 ^g	31.0 ^{fe}	1731.3 ^g	1660.0 ^f	35.4 ^f	46.1 ^e
100	0	4188.6 ^k	3994. ^k	28.6 ^{lk}	26.0 ^{ik}	1415.0 ^{lk}	1253.0 ^m	33.7 ^{kj}	43.8 ^{hji}
	2.5	4729.3 ^g	4492.0 ^f	34.0 ^e	31.3 ^{de}	1790.3 ^f	1633.0 ^g	33.7 ^{kj}	46.3 ^e
	5	5238.0 ^e	4891. ^d	34.0 ^e	32.3 ^{dc}	2138.3 ^e	1932.0 ^d	40.8 ^d	48.5 ^d
	7.5	5421.6 ^c	5029.3 ^c	36.0 ^d	33.3 ^{bc}	2236.6 ^c	2090.0 ^c	41.2 ^c	51.3 ^c
150	0	4189 ^k	3996 ^k	30.6 ^{il}	25.3 ^k	1415 ^{lk}	1360.3 ^l	33.7 ^{kj}	44.5 ^{hg}
	2.5	5672 ^b	5142 ^b	38.0 ^b	32.6 ^{ba}	2386.6 ^b	1790.6 ^e	42 ^b	51.1 ^b
	5	5724.6 ^a	5308.3 ^a	40.0 ^a	35.0 ^a	2483.6 ^a	2373.3 ^a	43.3 ^a	53.2 ^a
	7.5	5268.0 ^d	4526 ^e	37.0 ^c	32.6 ^{ba}	2149.0 ^d	1662 ^f	40.7 ^d	44.7 ^e
LSD		66.890	14.135	1.064	3.10	4.619	2.823	0.108	0.842
CV (%)		7.6	4.7	4.4	0.78	6.9	5	5.1	4.4

Where: ADB: above-ground dry biomass, HSW: hundred-seed weight, SY: seed yield, HI: harvest index, LSD: least significance difference, CV: coefficient of variance.

4. Conclusion

The field experiment demonstrated that the integrated application of coffee husk biochar (BC) and blended NPSB fertilizer substantially improved the growth, yield components, and productivity of common bean under acidic soil conditions at Kayikela (Bonga Town) and Kicho (Gimbo District), Kaffa Zone, Southwest Ethiopia. The combined application enhanced plant growth, phenological development, yield components, above-ground dry biomass, harvest index, and hundred-seed weight compared with the unfertilized control. The highest seed yields were obtained from the combined application of 5 t ha⁻¹ coffee husk biochar with 150 kg ha⁻¹ NPSB fertilizer, producing 2483.6 kg ha⁻¹ at Kayikela and 2373.3 kg ha⁻¹ at Kicho. Similarly, the highest above-ground dry biomass yields, 5724.6 and 5308.3 kg ha⁻¹, respectively, were recorded under the same treatment combination, demonstrating the potential of integrating organic amendments with balanced

mineral fertilization to improve nutrient availability and crop productivity in acidic soils. The results further indicate that the response of common bean to NPSB fertilizer varied between locations, highlighting the importance of site-specific nutrient management. In particular, the combined use of 5 t ha⁻¹ coffee husk biochar with NPSB fertilizer provided a promising strategy for improving productivity where phosphorus deficiency and soil acidity constrain common bean production. Biochar may complement mineral fertilizer by improving soil nutrient retention and the soil environment, while NPSB supplies readily available nutrients required for crop growth and grain formation. Thus, their integration offers a practical approach for increasing nutrient-use efficiency and exploiting locally available coffee-processing residues for soil fertility management. Based on agronomic performance and economic feasibility, 5 t ha⁻¹ coffee husk biochar combined with 150 kg ha⁻¹ NPSB fertilizer is recommended for common bean production at Kayikela, whereas 5 t ha⁻¹ coffee husk biochar combined with 100 kg ha⁻¹ NPSB fertilizer is recommended at Kicho under comparable acidic-soil conditions. These recommendations provide location-specific nutrient management options that can improve common bean productivity while promoting the beneficial utilization of coffee husk biochar. However, because the experiment was conducted during only one cropping season, multi-season and multi-location evaluations are recommended to verify the consistency, residual effects, and economic sustainability of these treatment combinations before wider-scale recommendation.

Author Contributions Statement

Isreal Zewide : conceptualization, investigation, software, writing—original draft, methodology, validation, visualization, formal analysis, and data curation. Tekalign Argaw conceptualization, methodology, validation, writing—review and editing, investigation, formal analysis, and data curation. Tamirat Wato: conceptualization, investigation, visualization, validation, data curation, writing—review, and editing

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All data were available upon reasonable request to the corresponding author.

Conflict of Interest

The authors declared that there is no conflict of interest.

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