



Research Article

Combination of Blended Fertilizer Rates and Row Spacing Variations Improving Common Bean Yield and Yield Components at Guji Zone, Southern Ethiopia

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Abstract

In Ethiopia, the productivity of common bean (*Phaseolus vulgaris* L.) is primarily limited by insufficient soil fertility and sub optimal plant spacing. Consequently, a field experiment was undertaken in southern Ethiopia to identify the most effective plant population and multi-nutrient fertilizer (NPS) application rate for achieving economically viable common bean yields. The experimental setup involved three intra-row spacing options (8cm, 10cm, and 12cm) combined with five levels of NPS application (0, 50, 100, 150, and 200 kg/ha). This was arranged in a randomized complete block design with three replications. The application of NPS fertilizer resulted in a decrease in soil pH. Concurrently, it led to an increase in soil organic carbon, total nitrogen, and the availability of sulfur and phosphorus. However, the cation exchange capacity of the soil remained unaffected. The application of 150 kg NPS ha⁻¹ and an intra-row spacing of 8 cm resulted in an optimal grain yield of 2505.56 kg ha⁻¹, with a net return of 19558.99 ETB ha⁻¹ and a marginal return rate of 93.35 percent. The best grain yield for both agronomic and economic growth and productivity for common beans was found when 150 kg of NPS was applied at an 8 cm plant spacing.

Keywords

Adola, Hegere, Intra Row, NPS, Soil fertility

1. Introduction

The common bean (*Phaseolus vulgaris* L.) is an annual herbaceous plant that was cultivated independently in ancient Mesoamerica and the Andes, and it is now cultivated globally for its dry seeds as well as for green bean consumption. Among the thousands of legume species, the common bean, in its various forms, is the most widely consumed by humans when compared to all other legumes [4]. In 2012, worldwide production included approximately 23.9 million tons of dry beans, 20.7 million tons of green beans, and 1.9 million tons of string or common beans [25].

legumes, following faba bean in terms of both cultivation area and yield [4]. Due to its quick maturation, nutritional profile, adaptability, resilience to adverse conditions, provision of food and income, as well as its crucial role in agricultural systems, this crop is identified as a key element for food security [5, 6]. The majority of common bean production in Ethiopia is concentrated in three regions (Amhara, Oromia, and the Southern Nations, Nationalities, and Peoples region), accounting for 97% of the total output [8, 9]. The production primarily

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takes place on smallholder farms that occupy around 0.31 million hectares, resulting in a yield of approximately 0.55 million tons, with an average productivity of 1.73 tons per hectare [11]. Nevertheless, this average productivity falls significantly short of the crop's genetic potential, which is projected to be ≥ 3 tons per hectare under optimal management conditions [18].

One of the main issues smallholder farmers in Ethiopia face is low fertility and agricultural productivity, which are caused by widespread soil degradation [13, 21]. Common bean yield is severely constrained by nutrient deficiencies and subpar agronomic practices, such as uneven fertilizer inputs and improper plant density [6, 12] of diamoniumphosphate (DAP), namely, blanket manure recommendations, for few legumes, to degree ordinary bean, has further donated to soil vitamin imbalances and decreases sterility and yield [23]. In addition to nitrogen and plant seen at dawn, incompetent chance of potassium, sulfur, boron, zinc, and law enforcement officer is coarse between Ethiopian soils [22, 23]. Given these imperfections, studies have signed harmonized fertilizers [7, 12] NPS, NPSB, and NPSZnB multi food fertilizers are hopeful for improving soil traits and crop output [34, 35]. NPS, NPSB, and NPSZnB multi-nutrient fertilizers are promising for progressing soil characteristics and edit efficiency [34, 35]. Sulfur containing multi-nutrient fertilizers, in specific, are exceedingly prescribed for vegetables [35], given the significance of sulfur in nitrogen obsession and ensuing photo assimilation, development, nodulation, and abdicate.

On the other hand, plant populace and course of action of plants in a unit zone enormously decides asset utilization such as light, supplements and water, the rate and degree of vegetative development and advancement of crops, improvement of vital maladies and bugs, conjointly the seed fetched [10]. Planting thickness and spatial course of action are fundamental agronomic components that have a conclusive affect on edit development, advancement, and last add up to generation [16]. Plant populace influences early ground cover, competitive capacity of crops, soil surface vanishing, light capture attempts, lodging and etc. It too influences canopy advancement, plant design and conveyance of cases [16]. Ideal plant thickness is the least populace that gives greatest abdicate and reasonable plant course of action per unit range, permitting crops to misuse asset ideally and deliver tall yields [10]. In any case, ideal plant thickness changes depending on trim assortments, tallness and branching, time of sowing, and the nature of the season [20].

Common bean assortments have distinction in development propensity and seed estimate. But only one plant density ($40 \text{ cm} \times 10 \text{ cm}$ or $250,000 \text{ plants ha}^{-1}$) has been adopted in Ethiopia; without considering rainfall amount and distribution, nature of varieties and climatic conditions [36]. In expansion to this, the conventional dividing of common bean in most zones counting Guji isn't uniform since agriculturists basically wide cast the seed arbitrarily to the arranged field. Notably, the best

density for a certain variety of crops is not the same everywhere and depends on the soil type and climate, management practices, and many other connected aspects [37]. Thus, site-specific recommendations, including the optimum density of plants, are needed to maximize crop productivity while maintaining the sustainability of agriculture.

Considering the decrease in soil fertility and generally common bean efficiency in Ethiopia [6, 12, 18] investigate centering on coordinates agronomic hones to oversee connect activities of different components might fortify current modeling endeavors and offer assistance address the multifaceted imperatives constraining common bean efficiency. In any case, there's constrained data vis-à-vis the impacts of shifting planting thickness and application rates of the as of late presented NPS fertilizer ($19 \text{ N-38 P}_2\text{O}_5\text{-7 S}$) on soil chemical properties, as well as the development, surrender components, and abdicate of common bean in southern Ethiopia. Subsequently, this test was carried out with the taking after goals to determine the intra row dividing, NPS fertilizer rates and their the interaction on development and surrender of common bean.

2. Materials and Methods

2.1. Description of the Study Area

Field trials were conducted at the Adola location of the Bore Agricultural Research Center in southern Ethiopia throughout the growing seasons of 2023, 2024, and 2025 (March and August). The research site is situated at an elevation of 1718 m above sea level at latitudes from $05^{\circ}50'0'' \text{ N}$ to $05^{\circ}55'0'' \text{ N}$ and longitudes from $38^{\circ}57'30'' \text{ E}$ to $39^{\circ}0'50'' \text{ E}$. The area experiences a bimodal rainfall pattern, characteristic of mid-altitude agro-ecology, featuring a prolonged rainy season from early March to August and a brief rainy season from early September to late November. In the cropping seasons of 2023, 2024, and 2025, the region experienced annual rainfall of 1176, 1143, and 1107 mm, respectively. During the experimental period, the average minimum and maximum temperatures varied between 12.9°C and 18.2°C , and 20.1°C and 26.4°C , respectively. The primary soil at the research location is Orthic acrisols (reddish brown soil), with a dominant brown color [14]. This soil is appropriate for cultivating key crops like teff, wheat, barley, maize, common bean, along with various fruits and vegetables, achieving a significant coverage of 70%. The soil features a clay composition with a pH around 6.4, classifying it as moderately acidic (Table 1).

2.2. Materials for Experimentation

The studies utilized a bush-type common bean variety known as Hegere, released in 2023 by the Bore Agricultural Research Centre, and reaches maturity in 91.12 days. The variety is appropriate for areas at elevations between 1450-1900m above sea level that experience 500-750 mm of evenly distributed rainfall each year throughout the growing season.

The average yields for the varieties ranged from 2.53 to 3.39 t ha⁻¹ at the research stations and from 2.15 to 2.73 t ha⁻¹ at the fields of farmers. This research employed an NPS fertilizer (19 N-38 P₂O₅-7 S).

2.3. Treatments and Experimental Setup

The trial utilized five fertilizer rates (0, 50, 100, 150, and 200 kg ha⁻¹) and three intra-row spacing's: 8, 10, and 12 cm, corresponding to plant densities of 781,250, 250,000, and 208,333 plants ha⁻¹, respectively. The experiment was designed using a randomized complete block design (RCBD)

with three repetitions of every treatment. The spacing between the rows was established at 40 cm across all plots. An experimental unit of 8.4 m² (3 x 2.8 m) plot area was utilized. Every plot contained 7 rows separated by 40 cm. One outermost row on each side of a plot and three plants (30 cm) at each end of the rows were designated as borders. A row adjacent to the border rows on either side was utilized for destructive sampling. Consequently, the total pot size was (1.6 m × 2.4 m = 3.84 m²) consisting of four rows, with each row containing 24 plants. Other agronomic activities such as hoeing, weeding, and controlling pests and diseases were maintained consistently across all the plots throughout the experimental duration.

Table 1. Fertilizer rates and their nutrient composition (kg ha⁻¹) used for the experiment.

No	Blended NPS Fertilizer rate (kg ha ⁻¹)	N	P ₂ O ₅	S
1	0 kg NPS	0	0	0
2	50 kg NPS	9.5	19	3.5
3	100 kg NPS	19	38	7
4	150 kg NPS	28.5	57	10.5
5	200 kg NPS	38	76	14

2.4. Data Gathering and Measurements

Days to flowering were calculated as the duration from planting until 50% of the plants in a plot start to bloom. The number of days to physiological maturity was recorded when 90% of the plants in each plot ceased to exhibit green pod coloration. Five randomly selected plants from each plot were measured for height from the base to the apex at physiological maturity. Pods per plant were calculated for five randomly selected plants from each plot. Seeds per pod were enumerated for five randomly chosen plants from each plot. Thousand seed weight (TSW) was measured by counting 1000 seeds using a seed counter and weighing them on a precise balance. Biomass yield was calculated by adding the weight of the straw to the total grain yield. The grain yield was collected from a net plot area and transformed into kg/ha after moisture content was adjusted to 10%. The harvest index (HI) was calculated in the following manner:

$$HI = \text{Yield of grain/Biomass yield.}$$

2.5. Methodology for Experiments and Crop Care

The experimental plot was established utilizing oxen-drawn tools (local plough maresha) following the traditional farming methods of the farmers. The field underwent ploughing three

times: the initial ploughing occurred at the end of May, the second took place in mid-July, and the third was completed in mid-August prior to planting the crop to achieve fine tilth. The plots were smoothed out by hand. The seeds were sown manually at a designated distance (40 cm × 10 cm), with two seeds in each hill, and then reduced to one plant per hill after they sprouted. The total needed quantity of blended NPS was utilized in the band during planting. Moreover, all essential cultural and agronomic practices were applied consistently across all plots according to the crop's recommendations during every phase of growth and development. The harvest was done by hand with a sickle once 90% of the leaves and pods had yellowed and dried in the sun for 4 days prior to threshing. Threshing was performed individually for each treatment by hand.

2.6. Collection and Examination of Soil Samples

Soil samples were taken two times during this study, each at depths of 0–20 cm. The initial sampling took place one week prior to the first plowing in March, where 20 randomly obtained cores were combined into one composite sample for laboratory testing. The second sampling took place in the second week of August in the third year following the crop harvest. These samples were gathered on a plot basis and forwarded for laboratory testing. The analysis in the laboratory took place at the Soil and Water Analysis Laboratory of Horticoop Ethiopia (Horticultural) PLC. The soil texture was

evaluated using the Bouyoucos hydrometer method [25]. The pH of the soil was measured using a pH meter in a 1: 2.5 soil to water mixture [38]. The content of soil organic carbon (SOC) was measured using the Walkley and Black method [19]. The total nitrogen (TN) level was assessed using the Kjeldahl method [17]. The NaHCO_3 extraction method [26] was used to determine the available phosphorus (AP). The Mehlich-3 method [27] was used to assess the levels of exchangeable potassium, magnesium, calcium, sodium, and available sulfur (AS). The soil cation exchange capacity (CEC) was measured after extraction with 1 M ammonium acetate [28].

2.7. Economic Analysis

An economic analysis was performed based on the method described in [43], utilizing the average prevailing market prices of inputs at planting and outputs at harvest. The expenses and advantages linked to the research were assessed per hectare in Ethiopian Birr (ETB). The total variable costs (TVCs) were calculated by averaging the costs of NPS fertilizer (70 ETB kg^{-1}) and the daily labor expenses for farm activities (110 ETB per man). To close the yield gap between

research and farmer field conditions, the common bean GY was modified to 10%.

2.8. Statistical Data Analysis

All the measured parameters were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD according to the General Linear Model (GLM) of Gen Stat 18th edition [11] and the interpretations were made following the procedure described by [15]. Least Significance Difference (LSD) test at 5% probability level was used for mean comparison when the ANOVA showed significant differences.

3. Results and Discussion

Soil properties of the study site before common bean planting

The soil at the study site had a clay texture with sand, silt, and clay contents of 38%, 26%, and 46%, respectively. The pH was moderately acidic [29]. The TN and organic carbon (OC) contents of the soil are categorized as low [30] cited by [8].

Table 2. Selected physio-chemical properties of the experimental soil.

Property	value	Rating	References
Clay (%)	46%		
Sand (%)	38%		
Silt (%)	16%		
Texture class	Clay		
pH (H_2O)	6.4	Moderately acidic	[29]
Total nitrogen (%)	0.02	Low	[30] as cited by [8]
Available P (mg kg soil^{-1})	6.47	Medium	[26]
Organic carbon (OC)	1.03	Low	[30] as cited by [8]
Available S (mg kg soil^{-1})	18.28	Medium	[39]
CEC ($\text{cmol (+) kg soil}^{-1}$)	12.73	Low	[24]
Exchangeable K ($\text{cmol (+) kg soil}^{-1}$)	0.46	Medium	[24]
Exchangeable Na ($\text{cmol (+) kg soil}^{-1}$)	0.126	Low	[24]
Exchangeable Mg ($\text{cmol (+) kg soil}^{-1}$)	0.561	Low	[24]
Exchangeable Ca ($\text{cmol (+) kg soil}^{-1}$)	4.075	Low	

The available P and S of the soil are intermediate according to the ratings of [26] and [39], respectively. The exchangeable Na^+ ,

Ca^{2+} , and Mg^{2+} contents and CEC of the soil are low, whereas the exchangeable K^+ content is moderate [24]; Table 2.

In general, the soil fertility at the study site is low [32]. However, for optimum common bean growth, fertile soil with good physical properties and a pH ranging from 5.5 to 6.5 is needed [31]. Hence, the soil fertility at the study site is sub-optimal, but the soil texture and pH at the study site are optimal for common bean growth. Low soil fertility frequently limits the growth and yield of common bean. According to [33], legumes need sufficient levels of nitrogen, phosphorus, potassium, and sulfur for healthy growth. Furthermore, high PDs adversely affect crowding and high root biomass, increase competition for nutrients, and ultimately reduce soil fertility (nutrient contents) [33]. As a result, it is justified to use NPS fertilizer and maintain an optimal planting density to

increase agricultural output and assure food security.

Days to flowering

The interaction of blended NPS rate and varieties had significant ($P < 0.05$) effect on days to 50% flowering, but the main effects of variety and blended NPS rate were found to be highly significant ($P < 0.01$) on days to reach 50% flowering. Significantly, longest days (46.67 days) to reach flowering was recorded due to application of 200 kg ha⁻¹ of blended NPS for intra row spacing of 10cm while the earliest days to flowering (38.33 days) was recorded due to intra row spacing of 12cm (Table 3). Wider intra row spacing of 12 cm was found to be early maturing as compared to the other varieties across all NPS rates.

Table 3. Mean plant height of common bean as influenced by NPS rate and intra row spacing.

Intra row spacing	NPS rate (kg ha ⁻¹)				
	0	50	100	150	200
8	45.33 ^{abc}	45.33 ^{abc}	45.33 ^{abc}	45.33 ^{abc}	46.33 ^{ab}
10	45.67 ^{abc}	45.00 ^{bc}	45.33 ^{abc}	45.67 ^{abc}	46.67 ^a
12	41.67 ^d	38.33 ^e	39.67 ^e	39.67 ^e	42.00 ^d
LSD (0.05)			1.58		
CV (%)			2.20		

Plant height

Results of analysis of variance showed that main effects of NPS rate was significant ($P < 0.05$) while main effect of intra-row spacing and interaction of NPS rate and intra-row spacing was not significant for plant height (Table 4). The maximum plant height (105.07 cm) was observed for 200 kg NPS ha⁻¹, while the lowest value (87.74 cm) was for the control treatment (Table 4). The plant heights recorded from the application of 0, 50, and 100 kg NPS ha⁻¹ were statistically parity (Table 4). The increase in plant height in response to increased application rate of NPS might be due to maximum vegetative growth of the plants under higher N availability and better root development due to sufficient availability of P which support plant to better nutrient absorption.

Table 4. Mean plant height of common bean as influenced by NPS rate and intra row spacing.

Treatments	Plant height (cm)
Intra-row spacing	
8 cm	93.12
10 cm	98.80

Treatments	Plant height (cm)
12 cm	99.34
LSD (0.05)	NS
NPS rate (kg ha ⁻¹)	
0	87.74 ^b
50	95.98 ^{ab}
100	92.78 ^{ab}
150	103.87 ^a
200	105.07 ^a
LSD (0.05)	12.60
CV (%)	13.60

In conformity with the current result, [3] found that plant height was significantly increased up to 160 kg N ha⁻¹. Also application of phosphorus at the highest level (120 kg P₂O₅ ha⁻¹) increased plant height. The promotion effect of high P level on plant height may be due to better development of the root system and nutrient absorption [2]. The increase in plant height might also be ascribed to better root formation due to

sulphur, which in turn activated higher absorption of N, P, K and sulphur from soil and improved metabolic activity inside the plant. Similar results were reported by [1] where sulphur level of 40 kg ha⁻¹ was found to increase the plant height, LAI, chlorophyll content and number of branches per plant of blackgram (*Vigna mungo*).

Number of pods per plant

Highly significant ($P < 0.01$) effects of NPS fertilizer application rate and significantly ($P < 0.05$) affected by interaction of NPS rate and intra row spacing respectively (Table 5). The highest number of pods per plant (13.83) was recorded for application of 150 kg NPS ha⁻¹ with intra row spacing of 10cm whereas the lowest value (7.72) was obtained from the unfertilized plot under intra-row spacing of 8cm (Table 5).

The increase in number of pods per plant with increased NPS rates might be due to enough supply of N, P and S amount which might have increased the formation of primary branches and height of the plant with a concomitant production of higher number of pods. The decrease in the number of pods per plant with an increase in plant density could be due

to increased competition between plants (intra specific competition) which eventually might have caused lowering in the number of pods per plant.

This study revealed that increasing the NPS fertilization rate with the lowest PD or using the highest NPS rate with the 10cm intra row spacing significantly increased pod formation in common bean, indicating an inherently low or sub-optimal soil fertility level at the experimental site. These increases in PN could be attributed to a better supply of nutrients and limited competition among the plants for resources, enhancing vegetative growth, photosynthetic assimilation, and dry matter accumulation in plants, subsequently leading to greater translocation of assimilates for yield formation. The increase in pod number in response to NPS fertilization combined with the optimum planting density (10 cm intra row spacing) in this study is comparable to the findings of [32], who reported greater pod production due to NPS fertilization at the optimum PD in common bean plants with sub-optimal soil fertility at Adola, Southern oromia.

Table 5. Mean number of total pods per plant of common bean as influenced by NPS rate and intra row spacing.

Intra-row spacing (cm)	Fertilizer Rate (NPS kg ha ⁻¹)					Mean
	0	50	100	150	200	
8	7.72 ^d	9.78 ^{bcd}	12.33 ^{ab}	12.72 ^{ab}	11.94 ^{ab}	10.90
10	8.56 ^{a-d}	11.40 ^{abc}	11.83 ^{ab}	11.94 ^{ab}	13.83 ^a	11.51
12	10.67 ^{a-d}	12.83 ^{ab}	12.39 ^{ab}	12.39 ^a	13.11 ^a	12.28
Mean	8.98	11.34	12.18	12.35	12.96	
CV (%)	17.10					
LSD (0.05)	3.33					

Hundred seed weight

Hundred seed weight was high significantly ($p < 0.01$) influenced by NPS fertilizer rate and significantly affected by interaction of both factors (Table 6). The highest hundred seed weight (31.47 g) was recorded for application of 200 kg NPS ha⁻¹ with intra-row spacing of 10cm, while the lowest value (26.73 g) was for the un-fertilized plot under narrow spacing of 8cm (Table 6).

The increase in hundred seed weight with increased rate of NPS application might be because of enhanced nutrient use efficiency by the crop at optimum levels of N, P and S since grain weight indicates the amount of resource utilized during critical growth periods. The increase in hundred seed weight

with an increase in intra row spacing might be wider spaced plants, that improved the supply of assimilates to be stored in the seed, hence, the weight of hundred seeds increased. The improvement in 100 seed weight with fertilizer application is in agreement with the finding of [32] who related the increment in 100-seed weight to the influence of cell division, phosphorus content in the seeds as well as the formation of fat and albumin. The increase in hundred seed weight as a result of increased P application might be attributed to important roles the nutrient play in regenerative growth of the crop [40], leading to increased seed size [41], which in turn may improve hundred seed weight.

Table 6. Mean number of hundred seed weight of common bean as influenced by NPS rate and intra row spacing.

Intra-row spacing (cm)	Fertilizer Rate (NPS kg ha ⁻¹)					Mean
	0	50	100	150	200	
8	26.73 ^e	28.30 ^{b-e}	29.67 ^{a-d}	30.17 ^{ab}	29.93 ^{abc}	28.96
10	27.73 ^{de}	28.73 ^{b-e}	29.80 ^{a-d}	29.20 ^{bcd}	31.47 ^a	29.38
12	27.78 ^{cde}	28.83 ^{b-e}	28.07 ^{b-e}	28.50 ^{b-e}	28.73 ^{b-e}	28.38
Mean	27.41	28.62	29.18	29.29	30.04	
CV (%)	4.50					
LSD (0.05)	2.18					

Total biomass yield

Analysis of the data revealed that intra row spacing by NPS fertilizer rate interactions resulted in significant differences on biomass yield (Table 7). Generally, biomass yield as affected by the interaction ranged from 4.53 to 16.27 t ha⁻¹. The highest above ground dry biomass yield (16.27 t ha⁻¹) was recorded for 200 kg NPS ha⁻¹ with intra-row spacing of 10 cm; while the lowest value (4.53 t ha⁻¹) recorded for the control plot with intra-row spacing of 10 cm (Table 7). The increase in total above ground dry biomass at the highest rate of NPS could be due to more availability of N, which may significantly increase height of the plant, pods number and overall vegetative growth of the plants. In line with [32] who reported that N applications increased shoot dry mass of common bean, dry

matter production of French bean increased significantly with the application of different levels of nitrogen and phosphorus fertilizers, the biological yield was enhanced due to micro-nutrient (Zn) respectively. Total biomass yield shown a slight increase with increased intra-row spacing up to 10 cm, beyond which it significantly decreased following the trend exhibited by grain yield. The increment in total dry biomass at the closer spacing might be due to more number of plants per unit area. Such a marked response of biomass yield to intra-row spacing in this study is in agreement with results from [32] who observed that there was increase in biomass yield with decrease in the row spacing because of higher populations per unit area of common bean at Adola.

Table 7. Mean number of above ground biomass (t ha⁻¹) yield of common bean as influenced by NPS rate and intra row spacing.

Intra-row spacing (cm)	Fertilizer Rate (NPS kg ha ⁻¹)					Mean
	0	50	100	150	200	
8	6.03 ^{fg}	11.01 ^{a-f}	12.28 ^{a-e}	15.58 ^{ab}	15.45 ^{ab}	12.07
10	4.53 ^g	7.61 ^{d-g}	7.08 ^{efg}	13.81 ^{abc}	16.27 ^a	9.86
12	6.06 ^{fg}	10.09 ^{c-f}	9.34 ^{c-g}	10.55 ^{b-f}	12.70 ^{a-d}	9.75
Mean	5.54	9.57	9.56	13.31	14.81	
CV (%)	29.9					
LSD (0.05)	5.28					

Grain yield

Grain yield was high significantly ($p < 0.01$) influenced by main effect of NPS fertilizer rate and significantly ($p < 0.01$) affected by interaction of NPS fertilizer rate with intra-row spacing (Table 8). The highest grain yield (2505.56 kg ha⁻¹) was recorded for application of 150 kg NPS ha⁻¹ with intra-

row spacing of 8 cm, while the lowest value (1383.33 kg ha⁻¹) was for the un-fertilized plot under narrow spacing of 8cm (Table 8).

Increases in grain yield at higher rates of NPS fertilizer rate could be attributed to increased growth of vegetative parts, such as branches and leaves, and yield components, such as

number of pods per plant, number of seeds per pod and hundred seed weight. Grain yield per unit area increased with closer intra-row spacing, which might be due to higher plant population, but yield of individual plants decreased probably due to intense inter plant competition for resources such as nutrients, water and solar radiation as manifested by high plant mortality, high level of pod abortion and low number of pods per plant at the highest density plant. The positive response of common bean yield to the interaction effect of a high NPS fertilization rate and low plant density indicated that the fertility

of the soil at the study site was low (Table 8). Consistent with this suggestion, [32] reported that high plant density can cause crowding, increase competition for nutrients, and ultimately reduce soil fertility. The significant increase in growth parameters and yield attributes and yields in response to optimum NPS fertilization rates, along with an increase in the optimum plant density, revealed that the soil at the study site was inherently deficient in available nutrients. This is possibly because of the continuous cultivation of the field, which leads to soil degradation and, ultimately, limited nutrient availability [42].

Table 8. Mean number of grain yield of common bean as influenced by NPS rate and intra row spacing.

Intra-row spacing (cm)	Fertilizer Rate (NPS kg ha ⁻¹)					Mean
	0	50	100	150	200	
8	1383.33 ^e	2111.11 ^{a-d}	2116.67 ^{a-d}	2505.56 ^a	2172.22 ^{a-d}	2057.79
10	1511.1 ^{de}	1533.33 ^{cde}	2133.33 ^{a-d}	2244.44 ^{ab}	2433.33 ^{a-d}	1971.11
12	1650.00 ^{b-e}	2177.78 ^{abc}	2005.56 ^{a-e}	2127.78 ^{a-d}	1766.67 ^{b-e}	1945.56
Mean	1514.81	1940.78	2085.19	2292.59	2125.07	
CV (%)	19.90					
LSD (0.05)	661.28					

Harvest index

Harvest index was high significantly ($P < 0.01$) affected by NPS rate and significantly ($P < 0.05$) influenced by interaction NPS rate and intra row spacing (Table 9). The highest HI (0.33) was recorded for nil application of fertilizer in intra row spacing of 10cm. The lowest HI (0.15) value was seen for 200 kg ha⁻¹ in wider intra row spacing of 12 cm which was statistically in parity with 150 kg ha⁻¹ with 8cm, 10cm and 12 cm

intra row spacing (Table 9). The increment in harvest index with rates of fertilizer is in agreement with the findings of [32] who related lower value of harvest index at low level of phosphorus application to poor development of plants at different growth stages of soybean. Dhanjal *et al.* (2001) also reported improvement in harvest index values of 31.60, 31.99 and 33.86% due to increasing N level zero to 60 and 120 kg N ha⁻¹ respectively.

Table 9. Mean number of harvest index of common bean as influenced by NPS rate and intra row spacing.

Intra-row spacing (cm)	Fertilizer Rate (NPS kg ha ⁻¹)					Mean
	0	50	100	150	200	
8.0	0.24 ^{a-d}	0.20 ^{bcd}	0.18 ^{cd}	0.17 ^{cd}	0.16 ^d	0.19
10	0.33 ^a	0.20 ^{bcd}	0.30 ^{ab}	0.18 ^{cd}	0.15 ^d	0.23
12	0.28 ^{a-d}	0.22 ^{a-d}	0.28 ^{abc}	0.21 ^{a-d}	0.15 ^d	0.23
Mean	0.28	0.21	0.25	0.19	0.15	
CV (%)	7.00					
LSD (0.05)	0.12					

Table 10. Summary of ANOVA for growth, yield and yield related attributes of common bean.

Source	Mean squares							
	Df	PH	NPPP	NSPP	HSW (g)	GY	AGBY (t ha ⁻¹)	HI
Block	2	740.5	12.17	0.25	14.92	916339	41.41	0.0035
IRTRS	2	178.2 ^{ns}	9.35*	0.034 ^{ns}	3.80 ^{ns}	51895 ^{ns}	25.78 ^{ns}	0.009 ^{ns}
NPS rate	4	488.0*	23.08**	0.083 ^{ns}	8.58**	780333**	118.8**	0.025**
INTRS × NPS rate	14	265.8 ^{ns}	9.22*	0.07 ^{ns}	4.14*	350871*	42.81**	0.0103*
Error	28	173.5	3.96	0.27	1.70	156326	9.98	0.005
CV (%)		13.6	17.1	9.10	4.50	19.90	29.90	7.00

Keys: degree freedom, PH=plant height, NPP-number of pods per plant, NSPP-number of seed per pods, HSW hundred seed weight, GY-grain yield, AGBY-above ground biomass yield, HI-harvest index, NS,* and ** non significant, significant at 5% and 1%, respectively.

Partial budget analysis

The partial budget analysis of the 15 treatments is shown below in Table 11. Based on this result, the highest net benefit of 19558.99 Birr ha⁻¹ was obtained with MRR of 93.35% from 8cm intra-row spacing and at 150 kg/ha of NPS fertilizer rates.

The highest MRR of 173901.50% was obtained with net field benefit of 20449.03 Birr ha⁻¹. According to CIMMYT [43], the minimum acceptable marginal rate of return (MRR%) should be between 50 and 100%.

Table 11. Partial budget analysis of effect of plant population and blended NPS fertilizer rate on common bean.

Treatment	AGY (kg/ha)	GR (ETB/ha)	TVC (ETB/ha)	NR (ETB/ha)	MRR (%)
8cm*0 NPS kg/ha	1245.00	18674.96	5200	13474.96	
10cm*0 NPS kg/ha	1359.99	20399.85	5205	15194.85	34397.90
12cm*0 NPS kg/ha	1485.00	22275.00	5210	17065.00	37403.00
8cm*50 NPS kg/ha	1900.00	28499.99	8941	17882.06	66.84
10cm*50 NPS kg/ha	1380.00	20699.96	8946	11753.96	D
12cm*50 NPS kg/ha	1960.00	29400.03	8951	20449.03	173901.50
8cm*100 NPS kg/ha	1905.00	28575.05	12442	16133.05	D
10cm*100 NPS kg/ha	1920.00	28799.96	12447	16352.96	4398.20
12cm*100 NPS kg/ha	1805.00	27075.06	12452	14623.06	D
8cm*150 NPS kg/ha	2255.00	33825.06	15943	9558.99	93.35
10cm*150 NPS kg/ha	2020.00	30299.94	15948	14351.94	D
12cm*150 NPS kg/ha	1915.00	28725.03	15953	12772.03	D
8cm*200 NPS kg/ha	1955.00	29324.97	19444	9880.97	D
10cm*200 NPS kg/ha	2190.00	32849.96	19449	13400.96	70399.70
12cm*200 NPS kg/ha	1590.00	23850.05	19454	4396.05	D

Keys: AGY-adjusted grain yield, GR-gross return, TVC- total variable cost, NR-net return, MRR- marginal rate of return NS,* and ** non significant, significant at 5% and 1%, respectively.

However, the MRR was used as a basis for the economic recommendation of agronomic practices based on CIMMYT

[43]. On the basis of these findings, an NPS fertilizer of 150 kg ha⁻¹ combined with 8cm intra row spacing is the most economical for the production of common bean in the study area. In agreement with this study [32] reported the highest net benefit with the application of 150 kg ha⁻¹ NPS compared with the control (0) treatment on common bean. Therefore, this study highlights the specific integrated agronomic practices that can significantly improve common bean productivity and farmer incomes, providing practical guidance for sustainable and economically viable agricultural strategies.

4. Conclusion

The major production variables that a producer can manipulate to influence the potential yield of a given crop are soil fertility, plant population, spacing, variety selection and crop management activities. Among those fertilizer rate and plant populations per a given area require special focus to maximize the yield obtained from improved varieties of crops. Results from the present study showed that the plant population and application of blended NPS fertilizer rate stimulated the growth and yield of green bean and to obtain maximum growth and yield, the economical plant population and application rate have been optimized.

The research revealed that NPS fertilizer application generally enhanced SOC and nutrient availability, although it tended to lower soil pH. Notably, applying 150 kg ha⁻¹ of NPS fertilizer significantly boosted common bean growth, yield components, and overall GY, especially when coupled with 8 cm intra row spacing. However, the optimum GY was achieved with 150 kg NPS ha⁻¹ in combination with optimum plant density (8cm). Furthermore, the economic analysis indicated that integrating 150 kg NPS ha⁻¹ with the optimum plant density offered the most profitable strategy for common bean production in soils with fertility limitations. Based on these findings, the study advocates for an integrated approach involving the application of 150 kg NPS ha⁻¹ in conjunction with a 8cm intra row spacing to improve soil fertility, maximize common bean productivity, and ensure sustainable and profitable farming practices in the study areas.

Abbreviations

AP	Available Phosphorus
AS	Available Sulfur
CEC	Cation Exchange Capacity
AGY	Adjusted Grain Yield
D	Dominated
ETB	Ethiopian Birr
GR	Gross Return
TVC	Total Variable Cost
NR	Net Return
MRR	Marginal Rate of Return

PH	Plant Height
NPP	Number of Pods Per Plant
NSPP	Number of Seed Per Pods
HSW	Hundred Seed Weight
GY	Grain Yield
AGBY	Above Ground Biomass Yield
HI	harvest Index
PLC	Private limited company
D	dominated

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Author Contributions

Deresa Shumi: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing

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Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Jawahar, S. V., Vaiyapuri, V., Suseendran, K., Kalaiyaran C., and Sriramachandrasekharan, M. V. 2017. Effect of sources and levels of sulphur on growth and yield of rice fallow blackgram (*Vigna mungo*). International Journal of Chemistry, ISSN: 2123-2845 (online). <http://irjc.petsd.org> (Accessed on 8 March 2017).
- [2] Hussain, N.; Khan, A. Z.; Akbar, H. and Akhtar, S. 2006. Growth factors and yield of maize as influenced by phosphorus and potash fertilization. Sarhad Journal of Agriculture, 22(4): 579-583.
- [3] Moniruzzaman M., Islam, M. R. and Hasan, J. 2008. Effect of N, P, K, S, Zn and B on Yield Attributes and Yield of French Bean in South Eastern Hilly Region of Bangladesh. Journal of Agriculture and Rural Development, 6 (1&2): 75-82.
- [4] Broughton, W. J., Hernandez, G., Blair, M., Beebe, S., Gepts, P. and Vanderleyden, J. 2003. Bean (*Phaseolus* spp.) model food legumes. Plant and Soil, 252: 55-128.
- [5] Kebede, E. (2020). Grain legumes production and productivity in Ethiopian smallholder agricultural system, contribution to livelihoods and the way forward. Cogent Food & Agriculture, 6(1), 1–20. <https://doi.org/10.1080/23311932.2020.1722353>

- [6] Etana, D., & Nebiyu, A. (2023). Response of common bean (*Phaseolus vulgaris* L.) to lime and TSP fertilizer under acid soil. *Heliyon*, 9(4), e15176. <https://doi.org/10.1016/j.heliyon.2023.e15176>
- [7] Tadesse, A., Shanka, D., & Laekemariam, F. (2022). Short-term integrated application of nitrogen, phosphorus, sulfur, and boron fertilizer and the farmyard manure effect on the yield and yield components of common bean (*Phaseolus vulgaris* L.) at Alle Special Woreda, Southern Ethiopia. *Applied and Environmental Soil Science*, 2022, 1–12. <https://doi.org/10.1155/2022/2919409>
- [8] Tekalign, T., Haque, I., & Aguayi, E. A. (1991). Soil, plant, water, fertilizer, animal manure and compost analysis (Working Document No. 13). International Livestock Centre for Africa (ILCA).
- [9] Miruts, F. (2022). Assessment of on-farm performance of common bean in central rift valley areas of Ethiopia. *Cogent Food & Agriculture*, 8, 1-9. <https://doi.org/10.1080/23311932.2022.2147629>
- [10] Moraghan, J. T., Etchevers, J. D. and Padilla, J., 2006. Contrasting accumulations of calcium and magnesium in seed coats and embryos of common bean and soybean. *Food Chemistry*, 95(4), pp. 554-561.
- [11] GenStat, 2012. GenStat Procedure Library Release. 15th edition. VSN International Ltd.
- [12] Dela, M., Shanka, D., & Dalga, D. (2023). Bio fertilizer and NPSB fertilizer application effects on nodulation and productivity of common bean (*Phaseolus vulgaris* L.) at Sodo Zuria, Southern Ethiopia. *Open Life Sciences*, 18(1), 20220537. <https://doi.org/10.1515/biol-2022-0537>
- [13] Fufa, A., Tessema, T., Bekeko, Z., & Mesfin, T. (2023). Wild sun flower interference in common bean fields in the Central Rift Valley of Ethiopia. *Agrosystems, Geosciences & Environment*, 6(2), e20377. <https://doi.org/10.1002/agg2.20377>
- [14] Geleta, G., Mengistu, U., Demissu, H., & Diribe, K. (2022). Identification and evaluation of agro-ecological variation in dry matter yield and nutritional values of local grasses used as livestock feed in Adola Reedde, Guji Zone, Ethiopia. *Journal of Applied Animal Research*, 50, 369–379. <https://doi.org/10.1080/09712119.2022.2080212>
- [15] Gomez, K. A., & Gomez, A. A. (1984). Statistical procedures for agricultural research (2nd ed.). Wiley.
- [16] Musana, R. F., Rucamumihigo, F. X., Nirere, D., & Mbaraka, S. R. (2020). Growth and yield performance of common bean (*Phaseolus vulgaris* L.) as influenced by plant density at Nyagatare, East Rwanda. *African Journal of Food, Agriculture, Nutrition and Development*, 20(4), 16249–16261. <https://doi.org/10.18697/ajfand.92.18700>
- [17] Jackson, M. L. (1958). Soil chemical analysis. Prentice-Hall Inc.
- [18] Tirfessa, T., Jalata, Z., & Lamessa, K. (2022). Influence of blended NPSB fertilizer on nodulation and yield performance of Rhizobium inoculated common bean varieties in acidic soil, western Ethiopia. *All Life*, 15(1), 1290–1303. <https://doi.org/10.1080/26895293.20222156625>
- [19] Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, 37, 29–38. <https://doi.org/10.1097/00010694-193401000-00003>
- [20] Mebrate, A., Zeray, N., Kippie, T., & Haile, G. (2021). Determinants of soil fertility management practices in Gedeo Zone, Southern Ethiopia: Logistic regression approach. *Heliyon*, 8(1), e08820. <https://doi.org/10.1016/j.heliyon.2022.e08820>
- [21] Chala, G., Kassa, S., Tadele, T., Assefa, K., Teshome, H., Agegnehu, G., Abera, W., Tibebe, D., Sileshi, G. W., & Erkossa, T. (2022). Yield response of tef (*Eragrostis tef*) to nitrogen, phosphorus, potassium and sulphur under balanced fertilization on Vertisols in different agroecological zones of Ethiopia. *Experimental Agriculture*, 58, E12. <https://doi.org/10.1017/S0014479722000114>
- [22] Loha, G., Silas, M., & Gidago, G. (2023). Effect of common bean (*Phaseolus vulgaris* L.) varieties and variable rates of potassium fertilizer on yield and yield-related traits at Areka, Southern Ethiopia. *Applied and Environmental Soil Science*, 2023, 1–8. <https://doi.org/10.1155/2023/5996945>
- [23] EthioSIS. (2016). EthioSIS soil fertility map. Ethiopian Agricultural Transformation Agency.
- [24] FAO. (2006). Plant nutrition for food security: A guide for integrated nutrient management (Bulletin No. 16). FAO.
- [25] Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal*, 54(5), 464–465. <https://doi.org/10.2134/agronj1962.00021962005400050028x>
- [26] Olsen, S., Cole, C., Watanable, F., & Dean, L. (1954). Estimate of available phosphorous in soil by extraction with sodium bicarbonate (USDA Circular No. 939). United States Department of Agriculture.
- [27] Mehlich, A. (1984). Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. *Communications in Soil Science and Plant Analysis*, 15(12), 1409–1416. <https://doi.org/10.1080/00103628409367568>
- [28] Chapman, H. D. (1965). Cation-exchange capacity. In A. G. Norman (Ed.), *Methods of soil analysis* (pp. 891–901). American Society of Agronomy. <https://doi.org/10.2134/agronmonogr9.2.c6>
- [29] Murphy, H. F. (1968). A report on fertility status and other data on some soil of Ethiopia (Experimental Station Bulletin No. 44). College of Agriculture HSIU.
- [30] Debele, B. (1980). The physical criteria and their rating proposed for land evaluation in the highland region of Ethiopia. Land Use Planning and Regulatory Department, Ministry of Agriculture.
- [31] Salcedo, J. M. (2008). Regeneration guidelines: Common bean. In M. E. Dulloo, I. Thormann, M. A. Jorge, & J. Hanson (Eds.), *Crop specific regeneration guidelines [CD-ROM]* (pp. 9). CGIAR System-wide Genetic Resource Programme.

- [32] Alemayehu, D., Shumi, D., Kebede, E., Daba, N. A., & Dechassa, N. (2025). Optimum plant density and inorganic fertilizer application improved selected soil chemical properties and common bean productivity in southern Ethiopia. *Agrosystems, Geosciences & Environment*, 8, e70079. <https://doi.org/10.1002/agg2.70079>
- [33] Divito, G. A., & Sadras, V. O. (2014). How do phosphorus, potassium and sulphur affect plant growth and biological nitrogen fixation in crop and pasture legumes? A meta-analysis. *Field Crops Research*, 156, 161–171. <https://doi.org/10.1016/j.fcr.2013.11.004>
- [34] Elka, E., & Laekemariam, F. (2020). Effects of organic nutrient sources and NPS fertilizer on the agronomic and economic performance of haricot bean (*Phaseolus vulgaris* L.) in Southern Ethiopia. *Applied and Environmental Soil Science*, 2020, 1–9. <https://doi.org/10.1155/2020/8853552>
- [35] Shanko, A. S., Gedebo, A., & Gebeye, A. H. (2020). Growth, nodulation and yield response of green bean (*Phaseolus vulgaris* L.) to plant density and blended NPS fertilizer rates at Alage, Central Rift Valley of Ethiopia. *African Journal of Agricultural Research*, 16(11), 1503–1513. <https://doi.org/10.5897/ajar2019.14505>
- [36] Bakure, S., Yoseph, T., & Ejigu, D. (2023). Effect of inter row spacings on growth, yield, and yield components of common bean (*Phaseolus vulgaris* L.) varieties in the Central Rift Valley of Ethiopia. *Advances in Agriculture*, 2023, 1–11. <https://doi.org/10.1155/2023/7434012>
- [37] Mashiq, P. K., Moatshe-Mashiq, O. G., Nkomazana, C., Safi, K., & Molosiwa, O. O. (2021). Agro-physiological and yield attributes of common bean (*Phaseolus vulgaris* L.) genotypes as affected by plant density in Botswana. *Journal of Agricultural and Crop Research*, 9(9), 230–235. https://doi.org/10.33495/jacr_v9i9.21.154
- [38] Carter, M. R. (1993). *Soil sampling and methods of analysis*. Lewis Publishers.
- [39] Bashour, I. I., & Sayegh, A. H. (2007). *Methods of analysis for soils of arid and semi-arid regions*. FAO.
- [40] Zafar, M., Abbasi, M. K. and Khaliq, A. 2013. Effect of different phosphorus sources on the growth, yield, energy content and phosphorus utilization efficiency in maize at Rawalakot Azad Jammu and Kashmir, Pakistan. *Journal of Plant Nutrition*, 36: 1915–1934.
- [41] Fageria, N. K. 2009. *The Use of Nutrients in Crop Plants*. CRC Press, Boca Raton, FL.
- [42] Fujisao, K., Khanthavong, P., Oudthachit, S., Matsumoto, N., Homma, K., Asai, H., & Shiraiwa, T. (2020). Impacts of the continuous maize cultivation on soil properties in Sainyabuli province, Laos. *Scientific Reports*, 10(1), 11231. <https://doi.org/10.1038/s41598-020-67830-9>
- [43] CIMMYT (International Maize and Wheat Improvement Center). (1988). *From agronomic data to farmer recommendations: An economics training manual*. CIMMYT.