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RESEARCH ARTICLE

# Yield and economics of bean (*Phaseolus vulgaris* L.) as affected by blended NPS fertilizer rates and inter row spacing at maenitgoldia, Southwest Ethiopia

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## Abstract

The common bean is one of Ethiopia's most economically important legumes. However, its national average yield remains lower than the potential yield obtained at research stations. This is because of low soil fertility, inappropriate plant spacing, disease and insect pest problems. As a result, this experiment was carried out during 2021 to investigate the impact of blended NPS fertilizer rates and spacing between crops on the growth and yield of common bean and to analyze the economic feasibility of blended NPS rates with common bean spacing. A four-factorial combination of mixed NPS levels (0, 50, 100 and 150 kg ha$^{-1}$) and three-row spacing (30, 40, and 50 cm) were used in a three-replicate randomized complete block design. After collecting that plant phenology, growth, yield, and yield attribute parameters were analyzed by using SAS version 9.3 software. The results revealed significant differences for the main effect of the NPS blended fertilizer, row spacings, and their interaction on most of the common bean's measured phenological, growth, yield, and yield attributes. However, neither the main effect nor the interaction effects affected seedling emergence. The combined use of 150 kg of mixed NPS ha$^{-1}$ with a row spacing of 40 cm resulted in a higher grain yield (2.5 t ha$^{-1}$) and maximum net benefit (41775 ETB ha$^{-1}$). Hence, it can be established that earlier mentioned NPS fertilizer rate and row spacing is a better choice for farmers in the area and similar agro-ecologies in order to achieve the highest possible grain yield and a higher net return.

**Keywords:** Intra-row spacing, interaction, blended NPS, inter-row spacing, yield.

## Introduction

Ethiopia's economy is largely driven by agriculture, which provides 80–85% of employment, 61% of exports, and 38.5% of GDP (Degaga and Angasu, 2017). A diverse agroecology allows Ethiopia to produce a wide variety of crops and farming systems. Nutritionally, grain legumes are a low-cost protein source that accounts for about 15% of protein consumption, and income as a high-value crop represents the third largest export after coffee and sesame (Wondwosen *et al.*, 2017**).** In addition, legumes improve soil fertility by fixing nitrogen through biological fixation, feed animals, control soil erosion, and providing fuel (Tarirai *et al.,* 2019). More recent data showed that the total national production of common beans in the country was estimated to be 0.52% (about 1,727,398.97 Qts) of common white beans and 0.93% (3,128,071.96 Qts) of common red beans in 2019/20, on a total area of 281,083.49 ha (CSA, 2020). The major common bean-producing regions include Oromia, the Southern Nations Nationalities and Peoples Region (SNNPR), and the Amhara Region. Oromia accounts for 51% of national common bean production, SNNPR accounts for 21%, and Amhara accounts for 24% (CSA, 2018). The leading broad bean producers in the southern region are Sidama, GamoGofa, and Wolayita (CSA, 2020).

The production and productivity of legumes are well below their potential in Ethiopia, despite the fact that increased legume production is expected to boost farm household income and contribute to improving household food security. This low yield of common bean in Ethiopia is attributed to a number of production constraints, including

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a lack of improved cultivars for the various agro-ecological zones, lack of agronomic practices such as poor soil fertility, crop rotation, premature and unsuitable field operations, unsatisfactory plant density, rainfall variability, insect pests and diseases (Habte *et al*., 2018). Therefore, appropriate production practices and precarious knowledge gaps need to be addressed to increase common bean production and productivity and their presence among smallholder farmers. Hence, mineral fertilizers with macro and micronutrients are available and required to ensure balanced fertilizer use by the crop grown as the application of these nutrients can dramatically improve fertilizer use efficiency and crop profitability (Elka *et al*., 2020). Fertility mapping of soil in Ethiopia showed that, in addition to N and P, major Ethiopian soils are deficient in K, S, Zn, B, and Cu, necessitating the application of customized and balanced fertilizers (Abera *et al*., 2017). To supplement the nutrient levels in the soil, use of blended NPS fertilizer is an important component in reducing yield losses caused by the nutrient. This is because a sufficient amount of phosphorus nutrition improves the physiological activities of legumes, including stimulating early rooting, growth, nodulation, photosynthesis, and flowering (Neenu *et al*., 2020).

The plant population and planning in a single area heavily influence resource utilization such as light, nutrients, and water, the rate and magnitude of vegetative and crop development, the development of major diseases and pests, and seed costs (Masa *et al*., 2017). Plant population also influences canopy development, plant architecture, pod distribution, early ground cover, crop competitiveness, soil surface evaporation, light interception, and housing (Khan *et al*., 2019). Optimal plant density is the minimum population that gives maximum yield and appropriate plant arrangement per unit area, allowing plants to make optimal use of resources and produce high yields (Ahmed *et al*., 2017). Furthermore, the traditional spacing of the common bean is not uniform in most areas, including the Goldia district, because farmers simply scatter the seed on the prepared field at random. The low common bean yield obtained by local farmers in the area reflects a lack of improved production technologies, mainly optimum spacing and recommended fertilizer rate. In light of this, optimum plant spacing and fertilizer requirements for crops at one location may differ from those at another location due to soil type, rainfall distribution, and nutrients available hence, determining optimal plant spacing as well as rates of NPS fertilizer is crucial to improve common bean productivity. However, little to no investigation has been conducted in the study area on the influence of mixed rates of NPS fertilizer and inter-row spacing on the growth and yield of common beans. Therefore, the present experiment was conducted to determine the best combination of fertilizer NPS and inter-row spacing to get the maximum yield.

## Materials and Methods

### *The Study Area's Description*

The field trial was held in the Meanit Goldia district during the year 2021. It is located 615 km south-west of Addis Ababa (the capital city), at 50″ 40′-70″ 40′ N latitude and 340″ 45′-360″ 10′ E longitude. The district has an elevation ranging from 1001–2500 m.a.s.l. with an average annual temperature ranging from 15 to 27°C. Mean annual rainfall ranges from 1500 to 1800 mm (an average of 1692 mm) (MG Agri. office, 2020). The rainfall pattern is bimodal, i.e., short rainy seasons (February and April) and long rainy season (June to October). The soil types of the research field are sandy, silty and clay-loam. The pH of soils ranges between 4 and 6 (Meanit Goldia Agri. office, 2020). The main stable food crops in the district include maize, grain Amaranthus, rice, groundnut, bean, pea, finger millet and Enset, while sorghum, teff, wheat and barley are cultivated to a significant extent. Fruits like bananas, pineapples and spices like coriander and ginger are among the cash crops in the area.

### *Soil Sampling and Analysis*

Twenty cm of soil depth was sampled randomly in zigzag fashion. Samples were air-dried, ground using a pestle and a mortar, and allowed to pass through a 2 mm sieve. The collected soil samples were combined into one sample, and working samples were extracted and analyzed from the composite sample. The following parameters were analyzed: cation exchange capacity (CEC), organic carbon, available phosphorus, total nitrogen, available sulfur, and soil pH using standard laboratory procedures.

### *Experimental Materials, Design and Treatments*

The common bean variety Nasir was used as a test crop since it adapted to the study areas and NPS fertilizers were used. NPS is compound fertilizer containing highly uniform granule of three important plant nutrients of nitrogen, phosphate, and sulfur with the ratio of 19% N, 38% $P_2O_5$, and 7% S. Four NPS (blended) fertilizer rates (0, 50, 100, 150 kg $ha^{-1}$) and three levels of inter-row spacing (30, 40, 50 cm) were arranged as factorial combinations. The field experiment was designed as a factorial randomized complete block design (RCBD) and replicated three times. Data were collected at random intervals from randomly selected tagged plants in the center. The border row was the outermost row from each side, and one plant from each end of the rows was also excluded to eliminate the border effect.

## Data Collection

### *Phenological Parameters*

*Days to emergence (DE)*

It was taken when half of the plants had emerged in the plot by visual observation.

*Days to 50% flower (DF)*

It was calculated as the number of days between sowing and the appearance of at least one open flower on 50% of the plants in a plot.

*Days to physiological maturity (DPM)*

It was determined as the days from specifying the starting time until the time when 90% of the plants in the field showed yellowing of leaves and drying of panicles.

### Growth Parameters

*Plant Height (PH)*

*It* was measured from the ground level to the terminal bud of the panicle at harvesting, taken from randomly fully grown five plants from the net harvestable plot area using a measuring tape.

*Number of Leaves (NL)*

The number of leaves per plant was counted by counting the number of fully expanded leaves on the sampled plants at physiological maturity.

*Leaf Area (LA)*

It was determined by measuring the length and width of the sample plants and as multiplied by 0.64 (LL*LW), LL=Leaf Length, LW=Leaf Width.

*Leaf area index (LAI)*

It was calculated by using the total leaves area divided by ground area.

leaf Area Index= Leafarea /Groundcover

*Number of Branches plant$^{-1}$ (NB)]*

It was counted from sampled plants at physiological maturity from net harvestable plot area and expressed in number.

*Number of total nodules plant$^{-1}$*

All nodules collected from randomly selected five plants in destructive rows counted at the flowering stage.

*Effective nodules plant$^{-1}$*

It was determined at 50% flowering by dissecting each nodule and observing the cross-section of the nodules. The nodules showing a strong pink to dark red color were considered as effective while those showing green, brown, or white color were considered as ineffective nodules.

### Yield and its components

*Number of pods plant$^{-1}$*

The tagged plants were harvested, pods on five plants were counted, and then the mean was obtained.

*Number of seeds pod$^{-1}$*

Five pre-tagged plants with pods were threshed from the harvested plants and was determined.

*Number of seeds plant$^{-1}$*

It was obtained by multiplying the pods number with number of seeds pod$^{-1}$.

*Biomass yield (BM)*

Approximately 10 days after gathering the plants in the net plot area, they were sun dried to a constant weight, and weighed by spring balance to obtain the total biomass yield and articulated in t ha$^{-1.}$

*Hundred-Seed weight (HSW)*

It was determined based on the weight of 100 seeds sampled from the grain yields of each treatment, using an electric seed counter, weighing with an electronic balance expressed by gram and accustomed to a moisture level of 10%.

*Grain yield (GY)*

The grain yield was calculated by harvesting and threshing the grain yield from the net plot area, converting it to kg ha$^{-1}$, and adjusting it to a moisture level of 10%.

*Harvest index (HI)*

It was calculated as a percentage of the grain yield per plot to the dry biomass yield per plot.

$$\text{HI (\%)} = \frac{\text{Grain yield}}{\text{dry biomass yield}} \text{ X } 100$$

### Statistical Data Analysis

After checking for normality, the data was subjected to variance analysis with SAS version 9.3 (SAS Institute Inc., 2015). At a 5% probability level, mean separations were performed using the LSD test. Pearson's correlation analysis was used to investigate the relationship between various parameters.

### Partial Budget Analysis

To consolidate the statistical analysis of the agronomic data, an analysis of partial budget was done for each treatment. Cost and return were calculated according to the CIMMYT (1988) for economic evaluation. During harvesting, haricot bean was evaluated at its usual open market price per kg.The mean yield of grain and straw data was adjusted by 10%, and partial budgeting and economic analysis were carried out per the CIMMYT partial budget methodology. Total variable costs (cost of fertilizers, row making, and planting) for each treatment were calculated and ranked in ascending order of total variable expense (TVC), and analysis of dominance was used to eliminate those treatments costing more but generating a smaller net benefit than the following lowest treatment. Net returns were calculated by deducting the cost of production from gross income. Non-dominated treatments have claimed that the greatest net benefit is to be economically profitable. The analysis of the partial budget was based on the formula developed by CIMMYT (1988) and given as follows.

*Gross average yield (Av.Y kg ha$^{-1}$)*

It is an average grain yield from each treatment.

*Adjusted yield (Aj.Y)*

A 10% adjustment was made to the average yield in order to reflect the difference between the experimental and the farmers' yield.

$$AjY=AvY-(AvY \times 0.1)$$

*Gross field benefit (GFB)*

It was calculated by multiplying the field/farm gate price that farmers receive when they sell the crop as adjusted yield (calculated both for grain and straw yield).

$$GFB=AjY \times \text{field/farm gate price for the crop}$$

Total variable cost (TVC) (ETB ha$^{-1}$) was calculated by summing up the costs that vary, including the cost of blended NPS (14.62 ETB kg$^{-1}$) and Urea (10.45 ETB kg$^{-1}$) fertilizers during planting time (August, 2020) and according to chat kebele farm daily payment of labor cost for row making, seed drilling and fertilizer application (8 person ha$^{-1}$, each of 43.75,50, 56.25 and 62.50 ETB day$^{-1}$ for 30,40 and 50 cm row spacing, respectively).

*Total cost*

It is the cost of fertilizers, row making and fertilizer application for the experiment. While the costs of other inputs and production practices remain constant and considered as insignificant among treatments.

*Net benefit (NB)*

was analyzed by deducting the total costs from gross field benefits for every treatment.

$$NB=GFB-\text{total cost}$$

*Dominance Analysis*

It was carried out by first listing all the treatments in their order of increasing costs that vary (TVC) and their net benefits (NB) are then put aside.

*Marginal Rate of Return (MRR) (%)*

It was carried out dividing change in net benefit (ΔNB) by change in total variable cost (ΔTVC) times hundred.

$$MRR = \frac{\Delta NB}{\Delta TVC} * 100$$

## Results and Discussion

### *Experimental site soil physicochemical properties*

The study site's soil was sandy clay loam with particle size distribution of 60% sand, 32% clay and 8% silt trough analysis of soil textural class determination triangle (Table 1). Thus, the soil texture of the study site is suitable for common bean production.

*Cation exchange capacity*

The outcome revealed that the cation exchange capacity of the experimental soil was 18.34 cmol (+) kg$^{-1}$ (Table 1). Landon (1991) classified CEC of 6, 6-12, 12-25, 25-40, >40 cmol (+) kg$^{-1}$ as very low, low, medium, high, and very high, respectively. Therefore, the CEC of the experimental soil is determined as medium.

*Total nitrogen*

Total nitrogen quantifies the total amount of nitrogen in the soil, the majority of which is stored in organic matter**.** The findings revealed that the total nitrogen content of the soil was 0.11% (Table 1). According to the classification of Kjeldahl method (ISO**,** 1995), total N 0.1% is classed as very low, 0.1–0.2% as low, 0.2–0.5% as moderate, 0.5–1% as high, and >1% as very high. Therefore, the total nitrogen content of the experimental soil is rated as low. Thus, the result indicated that N is the limiting factor for crop growth in the soil of the experimental site.

*Available Phosphorus*

The analysis revealed that the available P level in the research field soil was 7.08 ppm (Table 1). According to Bray and Kurtz (1945), the range of phosphorus in the Bray method is 7, 8–19, 20–39, 40–58, and >59, which is very low, low, medium, high, and very high, respectively. Based on this, the available phosphorous was very low. This very low phosphorous content is due to intensive mining of the farm fields and the fixation of iron, aluminum, and other elements. Ethio SIS (2014) suggests an optimum P content for most Ethiopian soils at 15 mg kg$^{-1}$. This also indicates that it needs external application of phosphorus fertilizer for good growth of the crop and yield. Overall, it was found that the experimental soils were conducive to common bean cultivation when external NPS fertilizer was applied.

*Sulfur*

The available sulfur value of the study area was 11.28 mg kg$^{-1}$(Table 1). Based on Ethio SIS (2014), soil classification for S values lies in a low range; according to it, 9 is very low, 10-20 low, 20-80 optimum, and > 80 mg kg$^{-1}$ high. So the addition of fertilizer, which contains S, is relevant. The soil's sulfur content is low, possibly due to organic matter loss and a lack of S-source mineral fertilizer use. It was also related to continuous cultivation, which resulted in the intensive removal of S from the soil.

*Soil pH*

Results indicated that soil was highly acidic with a pH value of 5.22 (Table 1). According to Ethio-SIS (2014), 4.5 is strongly acidic, 4.5-5.5 highly acidic, 5.6-6.5 moderately acidic, 6.6-7.3 neutral, 7.4-8.4 is moderately alkaline, >8.5 strongly alkaline.

**Table 1:** Soil description (physical and chemical) of the experimental site in 2021 main crop growing season

| *Soil property* | *Amount* | *Rating* | *References* |
|---|---|---|---|
| Particle size distribution (%) | | | |
| Sand (%) | 60 | | |
| Silt (%) | 8 | | |
| Clay (%) | 32 | | |
| *Textural class* | | *Sandy Clay loam* | *Brady and Weil (2002)* |
| pH(soil: water in 1:2.25) (W/V) | 5.22 | Highly acidic | Ethio SIS (2014) Ethio SIS (2014) |
| TN (%) | 0.11 | Low | Ethio SIS (2014) |
| Av. P(ppm) | 7.08 | Low | Ethio SIS (2014) |
| OC (%) | 0.93 | Very low | Ethio SIS (2014) |
| CEC (coml. (+) $kg^{-1}$ soil) | 18.34 | Medium | Ethio SIS (2014) |
| Av.S (ppm) | 11.28 | Low | |

*OC= organic carbon, TN= total nitrogen, Av.p (ppm)= available Phosphorus parts per million, CEC= cation exchange capacity, Av.S mg $kg^{-1}$ = available sulfur milligram per kilogram*

It was found that the optimum soil pH values ranging from 5.0 to 8.0 were recommended for common bean production. But soils with marginal values need some kind of amelioration. Thus, the pH of the soil at the experimental site would be made optimum for the production of common beans with appropriate soil management practices such as liming.

## *Phenological Parameters*

### *Days to 50% Flowering*

The NPS blended fertilizer rate had highly significantly affected ($P<0.01$) the days to flowering (50%). However, the sole consequence of row spacing and their interaction did not significantly influence flowering days ($P>0.05$). The application of 150 kg NPS $ha^{-1}$ resulted in the highest number of days (53.66 days) to reach flowering, while the shortest duration to flowering (41.77 days) was recorded for the control (Table 2). The current findings demonstrated that as the NPS blended fertilizer rate increased, days to flowering became longer due mainly to the extreme supply of N empowering luxuriant and succulent vegetative growth, dominating the reproductive phase. The outcome is consistent with that of Wondwosen *et al.* (2017) who stated that plots treated with 150 kg N $ha^{-1}$ reported a higher number of days to flowering (50%) as compared to 40 and 80 kg N $ha^{-1}$ in common bean. Similarly, Shumi *et al.* (2018) stated that an extended period to flowering date was observed by increasing the NPS rate from 50 to 200 kg $ha^{-1}$in haricot bean. Similarly, a report showed that increasing the level of NPS rate from 0 to 100 kg $ha^{-1}$ increased the number of days required to reach flowering from 39.61 to 44.11 days in common bean (Chinasho, 2017). Fekadu *et al.* (2021) also found that increasing the nitrogen application from 23 to 46 kg N $ha^{-1}$ significantly increased the number of days from sowing to flowering in chickpea.

**Table 2:** Effect of NPS (blended) fertilizer rates and row spacing's on Days to flowering (50%) and Days to physiological maturity (90%)

| *Treatments* | *DTF (day)* | *DTFM (days)* |
|---|---|---|
| NPS ($kgha^{-1}$) | | |
| 0 | $41.778^{c}$ | $83.33^{b}$ |
| 50 | $47.778^{b}$ | $88.33^{a}$ |
| 100 | $48.44^{ab}$ | $88.67^{a}$ |
| 150 | $53.667^{a}$ | $93.00^{a}$ |
| LSD (0.05) | 4.12 | 3.94 |
| Row spacing(cm) | | |
| 30 | $47.33^{a}$ | $87.75^{a}$ |
| 40 | $47.75^{a}$ | $88.33^{a}$ |
| 50 | $48.667^{a}$ | $88.917^{a}$ |
| LSD (0.05) | NS | NS |
| CV (%) | 8.99 | 4.56 |

*Where*: DTF= Days to flowering (50%), DTPM= Days to physiological maturity, Means in columns of the same parameter followed by the same letter(s) are not significantly different at 5% level of significance, LSD= least significant difference at $P<0.05$, CV= Coefficient of variation.

### *Days to 90% physiological maturity*

The main effect of blended NPS fertilizer rate on days to 90% physiological maturity was highly significant ($P<0.01$). However, the number of days to reach 90% physiological maturity did not demonstrate a significant ($P>0.05$) relationship between the primary effect of row spacing and their interaction. The application of 150 kg NPS resulted in the longest time (93.00 days) to reach 90% physiological maturity, whereas the application of 0 kg $ha^{-1}$ of blended NPS resulted in the shortest time (83.33 days) to bloom (Table 2). The results showed that days to maturity were generally extended in response to elevated levels of blended NPS, which can be attributed to the sulfur and nitrogen in the mixed fertilizer, which stimulate enzymatic activity and chlorophyll formation, which increases the amount of solar radiation intercepted, factors that influence growth parameters, foster plant development, and consequently lengthen days to flowering and physiological maturity. Application of N also delayed leaf senescence, maintained leaf photosynthesis throughout the active crop growth stage, and prolonged the growth of the vegetative period (Fekadu *et al.*, 2021). Similarly, Guo *et al.* (2021) reported a positive correlation between delay in leaf senescence, or the stay-green trait, and higher yield has been observed in cultivars of cereal crops such as maize in addition similar result was reported by Isreal *et al.* (2021) in potato plant.

## *Growth Parameters*

### *Plant Height*

The results showed that the blended NPS fertilizer rates' main and interaction effects were highly significant ($P<0.01$) for the height of common bean plants. The tallest plant height (82.00 cm) was recorded from the 150 kg NPS with 30 cm inter-row spacing, while the short plant (51.33 cm) was observed from the interaction of 0 kg ha$^{-1}$ of NPS fertilizer with 30 cm of inter-row spacing (Table 3). Increased blended NPS application rate results in increased plant height, it might be due to the plants' maximum vegetative growth under higher N availability and better root development due to sufficient P availability, which supports plant to better nutrient absorption and anchoring. Nitrogen aids chlorophyll formation, and sulfur enhances chlorophyll formation and encourages vegetative growth. This result is supported by the Adugna *et al.(*2020) who reported that phosphorus significantly increased the plant height at the application of 142 kg ha$^{-1}$ NPS on green beans.

*Leaf Area*

According to the result, the blended NPS fertilizer rates' main effect and interaction effect had a highly significant (P<0.01) impact on the common bean's leaf area, whereas the primary outcome of interrow spacing had no effect on the leaf area. Accordingly, the maximum leaf area (230.40 cm$^2$) was recorded from the combined effect of 150 kg NPS with 50 cm inter row spacing, while the minimum leaf area (107.50 cm$^2$) was recorded at 0 kg NPS with 30 cm interrow spacing (Table 3). This might be due to the increased cell elongation and enhanced vegetative growth, which was attributed to the fact that N is closely involved in the metabolism of plants which is essential for achieving optimal leaf area, the main indicator of the size of the assimilation system, which is maximized harvest solar radiation. The effects of increased phosphorus levels on growth parameters may also have resulted from improved nutrient uptake and root system development. This result is supported by Wondimkun *et al.(2022) who* reported that the maximum leaf area, which was higher than that of the other treatment combinations, was produced by applying 60 kg NPS per hectare with a spacing of 40*10 cm for mung bean plant.

*Leaf Area Index*

The blended NPS fertilizer rates' main effect and interaction effect had a highly significant (P<0.01) impact, while the effect of inter-row spacing was not significant (P>0.05) for common bean leaf area index. The highest leaf area index (17.43) was recorded from the combined effect of 150kg NPS with 50 cm inter-row spacing, while the minimum leaf area index (5.13) was recorded from 0 kg NPS with 30 cm inter-row spacing (Table 3). The increase in leaf area index with the increment of the rates of NPS fertilizer indicates maximum vegetative growth of the plants under higher NPS availability. This may play a crucial part in early root proliferation, which may boost the plant's ability to absorb nutrients, leading to higher vegetative development. This outcome agrees with Nuru *et al.* (2021) who reported that the application of 150 kg NPS and a 75 cm inter-row spacing resulted in the highest leaf area index of maize (43.1).

**Table 3:** NPS rate and inter-row spacing effects on plant height, leaf area, leaf area index and branches number

| *NPS Rate (kg ha$^{-1}$)* | *Inter raw spacing (cm)* | *PH (cm)* | *LA* | *LAI* | *NPB* |
|---|---|---|---|---|---|
| 0 | 30 | $51.33^{h}$ | $107.5^{j}$ | $5.13^{j}$ | $1.00^{f}$ |
| | 40 | $66.67^{fg}$ | $133.45^{h}$ | $7.73^{h}$ | $3.00^{e}$ |
| | 50 | $63.00^{g}$ | $163.84^{f}$ | $10.75^{f}$ | $4.00^{d}$ |
| 50 | 30 | $72.5cd^{ef}$ | $217.6^{b}$ | $16.1450^{b}$ | $4.67^{c}$ |
| | 40 | $71.00^{def}$ | $116.48^{ij}$ | $6.03^{ij}$ | $3.33^{e}$ |
| | 50 | $70^{ef}$ | $153.32^{g}$ | $9.71^{g}$ | $4.00^{d}$ |
| 100 | 30 | $75.33^{bcde}$ | $174.413^{e}$ | $11.83^{e}$ | $4.67^{c}$ |
| | 40 | $76.33^{abcd}$ | $195.84^{d}$ | $15.057^{c}$ | $5.67^{ab}$ |
| | 50 | $73.00^{dec}$ | $124.8^{hi}$ | $6.86^{hi}$ | $3.00^{e}$ |
| 150 | 30 | $82.00^{a}$ | $153.6^{g}$ | $9.74^{g}$ | $4.00^{d}$ |
| | 40 | $81.33^{ab}$ | $206.72^{c}$ | $13.96^{a}$ | $5.33^{b}$ |
| | 50 | $78.33^{abc}$ | $230.4^{a}$ | $17.425^{a}$ | $6^{a}$ |
| LSD(0.05) | | 6.082 | 9.141 | 0.914 | 0.619 |
| CV (%) | | 5.00 | 3.27 | 4.96 | 9.02 |

*Where:* PH= plant height, LA= Leaf area, LAI= leaf area index and NPB= number of primary branch.

*Number of Branches Plant$^{-1}$*

The results revealed that the major effects of blended NPS fertilizer rates, inter-row spacing, and their interaction had a highly significant (p<0.01) impact on the quantity of primary branches per plant. The uppermost prime branches per plant (6.00) was recorded from the combined effect of 150 kg NPS with 50 cm inter-row spacing, which was followed by a combined effect of 150 kg NPS with 40 cm. While, the minimum number of primary branches (2.67) was observed from the combined effect of 0 kg NPS with 30 cm inter row spacing followed by 40 cm of row-spacing with the same rate of NPS (Table 3). The increase in number of branches plant$^{-1}$ in response to an increased rate of NPS could result from the importance of P for cell division activity, leading to the increase of plant height and number of branches and the importance of S for growth and physiological functioning of plants and the easily available form of S that enhances nutrient uptake even at the early stages of crop growth may be the cause of the enlarged primary branches seen under mixed fertilizer. The results are consistent with those of Shumi *et al.* (2018) who noted a steady rise in the number of primary branches plants$^{-1}$ of common bean as mixed NPS fertilizer rates were increased from 0 to 250 kg ha$^{-1}$. Kibiru *et al.* (2018) also stated that the maximum number of branches plant$^{-1}$ was registered from inter-row spacing at 60 cm in soybean crop.

*Nodules Plant$^{-1}$*

The main effect of the blended NPS rate was very significant (P<0.01) on the total number of nodules per plant, while the main effect of inter-row spacing and interaction with

**Table 4:** Effect of NPS fertilizer rates on nodules numbers and effective nodules plant$^{-1}$

| *Treatments* | *NTPP (number)* | *ENPP (number)* |
|---|---|---|
| NPS (kgha$^{-1}$) | | |
| 0 | 67.78$^{c}$ | 15.33$^{c}$ |
| 50 | 67.78$^{b}$ | 19.33$^{b}$ |
| 100 | 69.00$^{b}$ | 21.78$^{b}$ |
| 150 | 75.78$^{a}$ | 29.56$^{a}$ |
| LSD (0.05) | 6.0481 | 3.85 |
| Row spacing(cm) | | |
| 30 | 68.58$^{a}$ | 29.17$^{a}$ |
| 40 | 69.25$^{a}$ | 29.08$^{a}$ |
| 50 | 66.42$^{a}$ | 28.83$^{a}$ |
| LSD (0.05) | NS | NS |
| CV (%) | 9.01 | 8.2226 |

NTPP= nodules number plant$^{-1}$, ENPP= effective nodules number plant$^{-1}$. Means in columns of the same parameter followed by the same letter(s) are not significantly different at 5% level of significance, LSD= least significant difference at P<0.05, CV= coefficient of variation.

the blended NPS rate had no significant impact on the total number of nodules. Thus, application of 150 kg NPS produced the most nodules per plant (75.77), while 0 kg NPS produced the least nodules (59.77) (Table 4). Greater NPS rate may have improved root development, which may explain why there are more nodules overall per plant at higher NPS rates. It could also be because of increases in the availability of phosphorus, which is required in relatively larger amounts to enhance plant growth, improve leaf area, nodules in certain legumes and yield. The current result is similar to Shumi *et al.* (2018), as the highest total nodules per plant was registered from applying 200 kg ha$^{-1}$ NPS fertilizer in common beans at Adola district, southern Ethiopia.

*Effective nodules plant$^{-1}$*

The main effect of blended NPS fertilizer rate was highly significant (P<0.01) for the number of effective nodules, but the main effect of inter-row spacing and its interaction with blended NPS were not significant (P>0.05). Thus, application of blended NPS fertilizer at the rate of 150 kg NPS ha$^{-1}$ produced the maximum effective nodules per plant$^{-1}$ (35.56), while 0 kg NPS ha$^{-1}$ produced the minimum number of effective nodules per plant (23.22) (Table 4). Due to phosphorus critical function in boosting nodule size, number, and nitrogen uptake per unit of nodules, there may have been a rise in the number of effective nodules with the increased application of NPS. In line with this, Mguez-Montero *et al.* ( 2020) reported that phosphorus plays a crucial part in increasing plant tip and root growth, decreasing the time needed for developing nodules to become active (effective) for the benefit of the host legume. Similarly, using 22 to 33 kg ha$^{-1}$ of nitrogen increased French bean nodulation and seed yield (Chekanai *et al*., 2018). The greater availability of sulphur and other important nutrients could potentially account for the greater number of effective nodules. According to Adugna *et al.* (2020), administration of sulfur, which is necessary for the development of a nitrogenous enzyme known to encourage nitrogen fixation in legumes, boosted the formation of nodules in black gram.

### *Yield and yield components*

*Pods Plant$^{-1}$*

The results showed that the main effects of blended NPS fertilizer rates and row spacing were very significant (P<0.01) for the number of pods produced per plant, but the interaction effects were not significant (P>0.05). The rate of 150 kg NPS ha$^{-1}$ resulted in the maximum number of pods per plant (22.89), while 0 kg NPS ha$^{-1}$ produced the lowest number of pods (16.56) (Table 5). A sufficient supply of N, P, and S may have boosted the development of primary branches and height of the plant, leading to a concurrent production of more pods, which may explain the increase in the number of pods per plant. Phosphorus fertilizer also encourages the formation of nodes and pods in legumes which is confirmed by the increase in the number of pods per plant as a result of P fertilizer application. This result is concurrent with Wondwosen *et al.*(2017) findings which indicated that the number of common bean pods per plant (31.37) significantly increased in response to increasing rates of phosphorus up to the highest rates (36.92 kg ha$^{-1}$). This outcome is also consistent with that of Shumi *et al.* (2018) who reported that the number of pods per plant of the common bean increased from 8.7 to 18.52 by increasing the NPS fertilizer from 0 to 250 kg ha$^{-1}$. Regarding row spacing, the highest (21.17) and lowest (19.25) number of pods per plant were recorded at 50 and 30 cm row spacing, respectively. Plants grown at wider spacing could have utilized their energy for more branching and, consequently, produced more pods per plant due to the reduced competition for light and reduced overlapping from adjacent plants. Furthermore, increased plant density induced competition between the former and later emerged flowers, which could lead to flower abortion and, thus, lower pod set. While wider intra row spacing might allow plants to retain more flowers and develop more lateral branches and pods, it might make it harder for individual plants to access growth factors (nutrients, moisture, and light) (Hasan, 2019). This outcome also complies with the work of Birhanu *et al.* (2018) who reported an increased pod number of mung beans at the wider inter-row spacing (40*15 cm) as compared to closer spacing (30*15 cm).

*Seeds pod$^{-1}$*

The main effect of blended NPS fertilizer rates on the number of seeds per pod was very significant (P<0.01), whereas the main effects of inter-row spacing and interactions with

**Table 5:** Effect of NPS (blended) fertilizer rates on pod number plant-1 and number of seeds pod$^{-1}$

| *Treatments* | *NPPP(number)* | *NSPP (number)* |
|---|---|---|
| NPS (kgha$^{-1}$) | | |
| 0 | 16.56$^{c}$ | 5.11$^{c}$ |
| 50 | 19.89$^{b}$ | 5.89$^{b}$ |
| 100 | 21.00$^{b}$ | 6.22$^{ab}$ |
| 150 | 22.89$^{a}$ | 6.67$^{a}$ |
| LSD (0.05) | 1.32 | 0.68 |
| Row spacing(cm) | | |
| 30 | 19.25$^{b}$ | 5.91$^{a}$ |
| 40 | 19.83$^{b}$ | 6.08$^{a}$ |
| 50 | 21.16$^{a}$ | 6.00$^{a}$ |
| LSD (0.05) | 1.15 | NS |
| CV (%) | 6.75 | 11.63 |

Where: NPPP= number of pods per plant, NSPP= number of seed per pod. Means in columns of the same parameter followed by the same letter(s) are not significantly different at 5% level of significance, LSD=least significant difference at P<0.05, CV=coefficient of variation

blended NPS were not significant (P>0.05). Thus, treatment of mixed NPS fertilizer at the rate of 150 kg NPS ha$^{-1}$ produced the maximum number of seeds per pod (7.05), while 0 kg NPS ha$^{-1}$ produced the lowest numbers (5.0) (Table 5). The increase in seeds per pod observed with increasing NPS fertilizer application rates may result from an adequate supply of nutrients facilitating the formation of nodules, protein synthesis, fruiting, and seeds. In line with the findings of Kaysha *et al.* (2020), mung bean plants that received 150 kg ha$^{-1}$ NPS fertilizer had the greatest number of seeds per pod (8.84). Similarly, Nuru *et al.* (2020) observed the most seeds per pod (7.1) while applying NPS to common beans at the rate of 100 kg ha$^{-1}$, but Shumi *et al.* (2018) revealed non-significant results for the number of seeds per pod in the common bean Beshbesh variety, which is in contrast to the current study.

*Hundred-grain weight*

The main effect of NPS fertilizer rates and the interaction were very significant (P<0.01) on the hundred-seed weight. However, the effect of inter-row spacing was not statistically significant (P>0.05). The maximum hundred-seed weight (57.61 g) was recorded for the application of 150 kg NPS ha-$^{1}$ with a 50 cm inter-row spacing, whereas the lowest value (51.23 g) was observed from the combined effect of 0 kg NPS ha$^{-1}$ with a 30 cm inter-row spacing (Table 6). The increase in hundred-seed weight with an 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 and could be explained by the important responsibilities that phosphorus plays in the crop's regenerative regeneration, which results in larger seeds and possibly improved hundred-seed weight. This is consistent with the findings of Wondwosen *et al.* (2017) who linked the increase in hundred-seed weight to the cell division and phosphorus content in the seed, as well as fat and albumin formation. Similarly, 150 kg ha$^{-1}$NPS application increased the thousand-seed weight of common bean (Shumi *et al.*, 2018). The outcome also agrees with those of Kaysha *et al.* (2020) who reported that NPS application up to 150 kg ha$^{-1}$ was claimed to have significantly increased mung bean thousand seed weights.

*Above-ground Dry Biomass*

According to the result, the main impacts of NPS and inter-row spacing as well as their interactions had a highly significant (P<0.01) impact on the above-ground dry biomass yield of common bean. With 50 cm row spacing, 150 kg of NPS produced the highest above-ground dry biomass yield (11.69 t/ha), while an unfertilized plot with 30 cm inter-row spacing produced the lowest dry biomass (5.87 t/ha) (Table 6). The increase in dry matter yield following the application of blended NPS fertilizer may probably be due to the appropriate supply of P, which may be linked to an increase in the number of branches plants$^{-1}$ which, in turn, increased photosynthetic area and the number of pods per plant, thereby increasing dry matter accumulation. As a primary nutrient, sulfur may have had a significant physiological impact by promoting cell division, growth, and chlorophyll biosynthesis, which enhanced assimilate output (Elka *et al.*, 2020). Also, according to Nebret et al. (2017), adding S increases nitrogen application efficiency. Nitrogen increases shoot dry matter, which is positively associated with grain yield in cereals and legumes (Wondwosen *et al.*, 2017). In line with the current findings, Oljirra *et al.* (2019) showed that the application of 150 kg ha$^{-1}$ NPS fertilizers significantly boosted the above-ground dry biomass weight of soybean bean (8151 kg ha$^{-1}$). The results of Geleta *et al.* (2022) also revealed a substantial linear response of above-ground dry biomass yield (5551 kg ha$^{-1}$) to NPSB application in faba bean on acidic nitisols. In contrast, the above-ground dry biomass of common bean was not affected by the introduction of sulphur up to 60 kg ha$^{-1}$ and nitrogen interaction with sulphur, according to Nebret (2017).

*Grain Yield*

The main effects of mixed NPS fertilizer rate, inter-row spacing, and their interactions on grain yield were highly significant (P<0.01). Accordingly, the maximum grain yield of 2.5 t/ha was recorded from the treatment combinations of 150 kg NPS ha$^{-1}$ with the highest (40 cm) inter-row spacing, while the unfertilized treatment with 30 cm inter-row spacing produced the lowest grain yield of 1.51 t/ha (Table 6). The outcome may be explained by the fact that using NPS fertilizer boosts crop development and output on naturally low NPS soils and soils depleted of NPS (Gemechu *et al.*, 2021). Current result is similar to the result reported by

**Table 6:** Combined effects of NPS (blended) rate and inter-row spacing on hundred seed weight, above ground biomass, grain yield, and harvest index

| *NPS Rate (kg ha$^{-1}$)* | *Interrow spacing (cm)* | *HSW* | *AGBM* | *GY (t ha$^{-1}$)* | *HI (%)* |
|---|---|---|---|---|---|
| 0 | 30 | 51.29$^{f}$ | 5.87$^{f}$ | 1.50$^{e}$ | 25.55$^{a}$ |
| | 40 | 53.26$^{d}$ | 6.7$^{ef}$ | 1.88$^{d}$ | 28.05 |
| | 50 | 55.67$^{b}$ | 8.7$^{bcd}$ | 1.84$^{d}$ | 21.14 |
| 50 | 30 | 57.59$^{a}$ | 9.7$^{abc}$ | 1.97$^{cd}$ | 20.30 |
| | 40 | 51.51$^{f}$ | 6.67$^{ef}$ | 1.93$^{cd}$ | 28.93 |
| | 50 | 53.44$^{d}$ | 7.95$^{cde}$ | 2.05$^{cb}$ | 25.78 |
| 100 | 30 | 55.56$^{b}$ | 10.67$^{ab}$ | 2.11$^{b}$ | 19.75 |
| | 40 | 57.61$^{a}$ | 11.03$^{a}$ | 2.38$^{a}$ | 21.57 |
| | 50 | 51.97$^{e}$ | 7.75$^{def}$ | 2.12$^{b}$ | 27.35 |
| 150 | 30 | 53.85$^{c}$ | 9.05$^{bcd}$ | 2.16$^{b}$ | 23.86 |
| | 40 | 55.62$^{b}$ | 10.75$^{ab}$ | 2.50$^{a}$ | 23.25 |
| | 50 | 57.62$^{a}$ | 11.69$^{a}$ | 2.48$^{a}$ | 21.21 |
| LSD(0.05) | | 0.39 | 1.993 | 0.14 | ns |
| CV (%) | | 0.43 | 13.23 | 3.96 | 29.93 |

HSW= hundred seed weight, AGBM= above ground biomass, GY= grain yield and HI= harvest index. Means in columns of the same parameter followed by the same letter(s) are not significantly different at 5% level of significance, LSD= least significant difference at P<0.05, CV= coefficient of variation

Habitamu *et al.* (2021) who found that application of S with or without P, recorded significantly higher seed yield (1325 kg ha$^{-1}$)up to 100 kg NPS ha$^{-1}$in chickpea. Increased amount of S, their availability alongside with other important nutrients, and higher crop uptake which ultimately led to effective, assimilate partitioning of photosynthates from source to sink in the post-flowering stage and resulted in the highest seed yield (Meleta *et al.*, 2021). This result might have resulted from enhanced root growth that increased the uptake of nutrients and water, favoring better growth due to the synergetic effect of the three (NPS) nutrients, which enhanced yield and its components. Phosphorus plays a crucial role in metabolism and energy-producing reactions and can withstand the adverse environmental effects. Birhanu *et al.* (2018) studies recommended that the widest inter-row spacing(40*15 cm) (lowest planting density) produced the highest grain yield. It was also suggested that mung bean plants compete excessively when planted at a high planting density narrower spacing (20*5 cm), leading to shorter, less vigorous plants and a smaller grain yield.

### *Partial Budget Analysis*

The data in Table 7 showed that the combined use of 40 cm between rows and a combined NPS fertilizer rate of 150 kg ha$^{-1}$ resulted in the greatest net benefit of 41775 ETB ha$^{-1}$, followed by a net benefit of 41415 ETB ha$^{-1}$ from the treatment consisting of a 150 kg ha$^{-1}$ NPS fertilizer combined with 50 cm of inter-row spacing. Therefore, it can be preferred that applying NPS at the right rate and inter-row spacing is a way to increase the economic value of using NPS fertilizer. The net benefit obtained by the use of 40 cm inter-row spacing with a rate of 150kg NPS ha$^{-1}$ was found to be greater than the net benefits obtained from applying blended NPS at any of the rates such as 0, 50, or 100 kg ha$^{-1}$ NPS combined with different inter row spacings. As a result, the mixture of 40 cm between rows and 150 kg ha$^{-1}$ NPS was the most appealing rate of fertilizer application for small-scale farmers in the study area, with low production costs and higher net benefit in this case. The analysis of partial budget indicated that five treatments (T3, T5, T9, T10, and T12) dominated all other treatments (T1, T2, T4, T6, T7, T8, and T11) and thus were selected for the analysis rate of return at the margin rate of return (MRR). The highest marginal rate of

**Table 7:** Partial budget analysis

| Treatments | | GY (kgha$^{-1}$) | AGY (kgha$^{-1}$) | TVC (Birr/ha) | GFB (Birr/ha) | NB (Birr/ha) | Dominance |
|---|---|---|---|---|---|---|---|
| 0 | 30 | 1500 | 1350 | 4909.5 | 27000 | 27000 | ND |
| | 40 | 1880 | 1908 | 4946.5 | 33840 | 33840 | ND |
| | 50 | 1840 | 1737 | 5094.5 | 33120 | 33120 | D |
| 50 | 30 | 1970 | 1944 | 6682.5 | 35460 | 34385 | ND |
| | 40 | 1930 | 1845 | 6934 | 34740 | 33665 | D |
| | 50 | 2050 | 1692 | 7100 | 36900 | 35825 | ND |
| 100 | 30 | 2110 | 1899 | 8692.5 | 37980 | 35830 | ND |
| | 40 | 2380 | 1656 | 8723.5 | 42840 | 40690 | ND |
| | 50 | 2120 | 2250 | 8810 | 38160 | 36010 | D |
| 150 | 30 | 2160 | 2232 | 10469.5 | 38880 | 35655 | D |
| | 40 | 2500 | 1773 | 10572 | 45000 | 41775 | ND |
| | 50 | 2480 | 2142 | 10725.5 | 44640 | 41415 | D |

*GFB= growth field benefit, AGY= average grain yield, AjY= adjusted yield, NB= net benefit, TVC= total variable cost (such as, Cost of NPS (21.5 ETB/ kg), row making, planting and fertilizer application cost were 14, 21 and 28 person's ha$^{-1}$, each of 70ETB day$^{-1}$ for 30, 40, 50cm row spacing respectively. NB= net benefit. Sale price of common bean at study area was Birr 45.25 per kg.*

**Table 8:** Marginal rate of return from blended NPS fertilizer rate and inter raw spacing

| *Treatments* | | *NPS Rate (kg ha$^{-1}$)* | *MC* | *NB (ETB)* | *MNB* | *MRR (%)* |
|---|---|---|---|---|---|---|
| *NPS* | *Spacing* | | | | | |
| 0 | 30 | 1500 | 3005 | | 27000 | |
| 0 | 40 | 1880 | 4008 | 1003 | 33840 | 6840 |
| 50 | 30 | 1970 | 4714.5 | 706.5 | 34385 | 545 |
| 50 | 50 | 2050 | 5802.5 | 1088 | 35825 | 1440 |
| 100 | 30 | 2110 | 5978.5 | 176 | 35830 | 5 |
| 100 | 40 | 2380 | 6833 | 854.5 | 40690 | 4860 |
| 150 | 40 | 2500 | 8070 | 1237 | 41775 | 1085 |

*Where: TVC = Total variable cost, MC = Marginal costs, NB = Net benefits, MNB = Marginal net benefits, MRR = Marginal rate of return, 1 Ethiopian Birr=0.027USD*

return was recorded from (T12) (6840%), followed by (T18) (4860%), and (T11) (1085%). However, as per CIMMYT (1988), all the non-dominated treatments produced a rate of return above the minimum acceptable level (50–100%). Therefore, the treatment comprising application of 150 kg ha$^{-1}$ NPS fertilizer with 40 cm (T11) was found to provide the highest net benefit compared to other nutrient integration ratios tested in this study, and its MRR is well above the lowest acceptable limit. Thus, this treatment can be regarded as the best treatment in terms of its economic return (Table 8).

## Conclusionw

The agronomic data of the current experiments revealed that almost all parameters had significant differences due to either the main or the combined impact of NPS and row spacing, except days to seedling emergence, which was not significantly affected by different levels of factors. A highly significant difference was observed on days to flowering, physiological maturity, total number of nodules, effective number of nodules, number of pods and number of grains per pod due to the main effect of blended NPS fertilizer rates. The mean maximum and minimum days to flowering (53.67% and 41.78 days), physiological maturity (93.00 and 83.33 days), total number of nodules (75.78 and 67.78), effective nodules (29.56 and 15.33), number of pods per plant (22.89 and 16.56) and number of grains per pod (6.67 and 5.51) were attained at 150 kg NPS ha$^{-1}$ and the lowest (0 kg ha$^{-1}$) blended NPS fertilizer application, respectively.

Most of common beans' growth, yield, and yield-related parameters were significantly impacted by the interaction between blended NPS fertilizer and row spacing. The interaction between NPS and row spacing had a highly significant impact on grain yield, number of branches, leaf area, leaf area index, and hundred-seed weight, whereas it had a only significant impact on plant height, above-ground biomass, and harvest index. The combination of 150 kg of blended NPS ha$^{-1}$ with 50 cm of row spacing yielded the maximum leaf area (230.4 cm$^2$), leaf area index (17.42 cm$^2$), number of branches (6.00), seed weight (57.62 g), and above-ground biomass yield (11.69 t ha$^{-1}$). Combined use of 150 kg NPS ha$^{-1}$ and 40 cm row spacing gave a maximum grain yield (2.5 t ha$^{-1}$).

According to the economic analysis, inter-row spacing of 40 cm with the application of 150 kg ha$^{-1}$ blended NPS produced the maximum net profit (41775 Birr ha$^{-1}$), while inter-row spacing of 30 cm with no fertilizer application produced the lowest net benefit (27000 Birr ha$^{-1}$). Therefore, 150 kg of NPS per hectare mixed application with 40 cm of inter-row spacing can be suggested for better growth, yield, and yield-attributing characteristics of common bean for Meanit Goldia and areas having similar agroecologies and soil types.

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