

Research Article

# Yield Components and Yield of Common Bean (*Phaseolus vulgaris* L.) Varieties as Influenced by Rates of Phosphorus at Yabello, Southern Oromia, Ethiopia

Gutema Idossa Olika<sup>1,\*</sup> , Demisachow Tadela Ayana<sup>1</sup>, Nano Alemu Daba<sup>2</sup>

<sup>1</sup>Yabello Pastoral and Dryland Agriculture Research Centre, Oromia Agricultural Research Institute, Addis Ababa, Ethiopia

<sup>2</sup>School of Plant Science, College of Agriculture and Environmental Science, Haramaya University, Dire Dawa, Ethiopia

## Abstract

Common bean is one of the economically most important legume crops grown in Ethiopia. One of the main factors limiting the productivity of common beans in the southern region of Oromia is poor soil fertility. The study was carried out to determine the effect of phosphorus fertilizer rates on common bean growth and production as well as to pinpoint commercially viable treatments that can increase common bean productivity. Three common bean varieties (Hawasa dume, Ado, and Batu) and five phosphorus levels (0, 23, 46, 69, and 92 kg P ha<sup>-1</sup>) were arranged in a factorial combination design with three replications in an RCBD. The study's findings indicated that the main effects of common bean varieties and phosphorus application rates were considerably influenced days to 50% flowering, days to maturity, plant height, and number of primary branches per plant. However, only the primary effect of P rates had a substantial effect on the harvest index. On the other hand, the interaction effect of phosphorus fertilizer rates and common bean varieties had a significant impact on the number of seeds per pod, number of pods per plant, total number of nodules per plant, total number of effective nodules per plant, hundred seed weight, grain yield, and aboveground biomass yield. The Hawasa dume variety, at 69 kg P ha<sup>-1</sup>, had the highest seed yield (2777.10 kg ha<sup>-1</sup>), whereas the Batu variety, without P application, had the lowest seed yield (1,718.73 kg ha<sup>-1</sup>). Additionally, correlation analysis demonstrated a positive and substantial relationship between seed yield and the majority of yield-related traits. The application of phosphorus fertilizer at 46 kg P ha<sup>-1</sup> resulted in the maximum net benefit (120,856 ETB ha<sup>-1</sup>) and MRR (1144.44 %) according to economic analysis. According to this study, applying phosphorus fertilizer may help promote high nodulation, yield, and growth of common beans. Thus, it can be said that for common production in the Yabello district, the application of phosphorus fertilizer at 46 kg P ha<sup>-1</sup> is advised. To get a final suggestion, it is advisable to repeat the experiment throughout several seasons and places, as it was only carried out for one season at a single location.

## Keywords

Effective Nodules, Growth, Grain Yield, Harvest Index, Phosphorus, Rate

\*Corresponding author: [idosagutema@gmail.com](mailto:idosagutema@gmail.com) (Gutema Idossa Olika)

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## 1. Introduction

Common bean (*Phaseolus vulgaris* L.) Is one of the legumes that is most commonly consumed worldwide. Grown for human consumption immediately, the crop is more valuable commercially than all other legume crops put together [21]. It is grown on practically every continent in the world in order to supply 50% of the grain legumes used as a source of protein worldwide. Furthermore, it is an annual legume that is primarily farmed for its abundant supply of vitamins, minerals, dietary fiber, protein, and complex carbohydrates [8]. It also serves as a rotation crop with cereal, reducing soil pathogens and supplying nitrogen to the cereal crop [28].

The country's low crop yield is ascribed to several factors, including the main ones are decreasing soil fertility, pest attack, variable rainfall and drought, and inadequate agronomic methods [14, 19]. Additionally, one of the factors limiting yield in grain legumes is the inadequate availability of vital nutrients for plants, particularly P [16]. Production obtained from common beans at Borana zone is approximately 447.35 ha with a total production of 474.19 tons and average productivity of 1.06 t ha<sup>-1</sup> [6].

In the tropical zone of cultivation, phosphorus is thought to be the most important plant nutrient, followed by nitrogen [1]. Furthermore, phosphorus is essential for the biological fixation of nitrogen [29]. The energy provided by the sugars that must be transferred downward from the host plant shoots is necessary for the processes of bacterial growth, nodule formation, and biological nitrogen fixation activity [17]. Thus, phosphorus is the building block of usable energy, which is necessary for the translocation and synthesis of sugars [16]. According to Senait, Shimels, common bean crops that rely on nitrogen fixation require a higher amount of inorganic phosphorus than those that get mineral nitrogen [22].

Some researchers looked at the effects of appropriate phosphorus rates on common bean yield and yield components; however, the recommended rates differ greatly from one another. This could be because of the soil's nutrient content, the study area's climate, the presence of pests, or the use of effective varieties. It has been proposed that applying phosphate fertilizers will increase crop yields and soil P availability [29]. Applying sufficient amounts of P is one way to increase bean yield in P-deficient soils [9]. Moreover, diverse research outcomes suggest that beans react differently to varying P rates in different places. According to [7], the crop produced its maximum seed production when P was applied at the rates of 69 kg P ha<sup>-1</sup> at Areka and 23 kg P ha<sup>-1</sup> at Kokate. The maximum seed yield and yield components were recorded by [27] on Nitisols at Boloso Sore and Damot Woreda in the Wolayita Zone, at 69 kg P ha<sup>-1</sup>. On the other hand, [3] found that at Arbaminch, applying 20 kg P ha<sup>-1</sup> resulted in the highest seed yield and associated yield metrics for common beans. In

addition, [25] Also mentioned that on Areka acidic soil, applying 2.7 t lime ha<sup>-1</sup> and 30 kg P ha<sup>-1</sup> had increased seed yield and economic return.

In the study area, several improved common bean varieties have been adapted and a significant role of this commodity among agro-pastoral as a major staple food has been recommended. On the contrary, none of the research incorporated phosphorus, which is considered to be the primary limiting factor in fulfilling the nutrient requirements of common beans. Consequently, agro-pastoral farmers have been applying a blanket recommendation rate of inorganic fertilizer without considering nutrient use efficiency, which has resulted in a very low seed yield per hectare.

Likewise, in addition to P fertilizer application, the selection and evaluation of common bean varieties to be P-efficient is essential to ensuring many small-scale farmers' financial security. Applying P fertilizers from outside sources according to the crop's prescribed rate could be one way to solve the issue [10]. A nutrition rate experiment is required in order to provide a precise P prescription for common bean production at a specific location. This indicates the absence of a well-known recommendation on phosphorus rates. Thus, the objectives of this study was to determine how phosphorus affects common bean growth and yield and to evaluate the viability of different common bean cultivars in relation to phosphorus fertilizer rates economically.

## 2. Materials and Methods

### 2.1. Description of the Experimental Site

The field experiment was carried out in 2023 during the main rainy season at the Yabello Pastoral and Dry Land Agriculture Research Centre (YPDARC) on-station in the Borana Zone of the Oromia Region. The trial site is situated in southern Oromia, 570 kilometers along the main route that connects Addis Ababa and Moyale. Situated at 045°3'24.2" N latitude and 038°06'22.3" E longitude, the Experimental site is 1729 meters above sea level. There are two distinct types of rainfall in the area: a long rainy season that lasts from March to May and peaks in April, and a short rainy season that lasts from September to November and is followed by a lengthy dry season. There are frequent crop failures in the area due to the erratic, low, and unpredictable rainfall distribution. The average annual temperature of the area is between 19.3 °C and 20.6 °C, and the annual rainfall ranges from 500 to 700 mm. The most pressing issue of the areas is a moisture deficit.

### 2.2. Experimental Materials

Three well adapted and high yielder bean varieties viz.,

Hawasa Dume, Batu, and Ado were used as test crops, and Triple Super Phosphate (46%  $P_2O_5$ ) was used as a source of P fertilizer.

### 2.3. Treatments and Experimental Design

The experiment comprised of two factors, namely, three common bean varieties (Hawasa dume, Ado, and Batu) and five different levels of phosphorus (0, 23, 46, 69, and 92 kg P  $ha^{-1}$ ). In a randomized complete block design with three replications, the treatment was set up as  $3 \times 5$ . The gross plot comprised six rows, each measuring 3m in length and 2.1m in width respectively. One row was left as a border row on either side of the plot, while the central four rows served as the net plot size and used for data collection.

### 2.4. Experimental Procedures and Field Management

A tractor was used to plough, disk, and harrow the ground. Every cultural practice was implemented consistently for every experimental plot in accordance with the guidelines.

35 cm by 15 cm inter and intra spacing was used. During planting, TSP (46%  $P_2O_5$ ), a phosphorus fertilizer, was calculated at an appropriate rate and administered during planting. Plots and blocks were separated by 0.8 and 1.5 meters, respectively. Two seeds were sown per hill and then thinned to one plant after seedling emergence. Before each plot was threshed, the crop was sun-dried and harvested when 90% of the leaves and pods were yellow.

### 2.5. Soil Sampling and Analysis

Prior to the field experimentation, ten random samples (0-20cm depth) were collected and a composite soil sample was prepared in the laboratory. These composite samples were used for soil physical and chemical analysis. The soil samples were oven dried, sieved to pass through 2 mm sieve, and placed in labeled plastic bags. The soil samples were oven-dried and ground to pass 2- and 0.5-mm sieves (for total N). All samples were analyzed following standard laboratory procedures. Organic carbon, total N contents of the soil was determined following the wet combustion method of Walkley and Black, and wet digestion procedure of Kjeldahl method, respectively. The available P content of the soil was determined following Olsen method. Soil texture was analyzed by Bouyoucos hydrometer method. The pH (1:2.5 solid: liquid ratio) of the soils was measured in water using pH meter with glass calomel combination electrode.

### 2.6. Crop Data Collection and Measurements

Phenological and growth, yield, and yield components parameters like days to flowering, days to maturity, total nodule number  $plant^{-1}$ , plant height (cm), number of pods  $plant^{-1}$ , number of seeds per pod, hundred seed weight (g), grain yield ( $kg\ ha^{-1}$ ), above ground dry biomass yield ( $kg\ ha^{-1}$ ) and Harvest index (%) were collected.

### 2.7. Data Analysis

R software version 4.2 was used to do an analysis of variance on all the gathered parameters. The means were compared using the Least Significance Difference (LSD) test at the 5% level of significance [11]. To examine the relationship between various parameters, Pearson's correlation analysis was also carried out.

### 2.8. Partial Budget Analysis

An analysis of the partial budget was conducted in order to look at the treatments' economic viability. Using the methods outlined by [5], economic assessments were conducted to compare the viability of the various treatments. To provide farmers with what they would get, the average yield was reduced by 10%. Variable costs were taken into account when doing a partial budget analysis.

## 3. Results and Discussion

### 3.1. Physico-Chemical Properties of the Experimental Soil Before Sowing

Prior to planting, a laboratory investigation of a few specific soil parameters at the experimental location reveals that, Particle size distribution showed that the soil had a composition of 54.28% sand, 20.72% clay, and 30% silt. (Table 1). The soil at the experimental site is classified as sandy clay loam using the soil textural class determination triangle. The soil pH of the testing sites is 6.15, according to the data. Thus, the chemical response of the experimental soil is graded as mildly acidic based on [24] (Table 1). The experimental soil has a moderate level of organic carbon (0.48%), according to rating done by [13].

The result of laboratory also showed that the experimental sites' overall N content was 0.14%, which might be considered poor. According to [24]. The available P in the experimental soil was 13.08 mg P  $kg^{-1}$  soil or 5.68 ppm of soil (Table 1). According to [24] rating, the available soil P was rated as low. The result also showed that the soil of the experimental site had low CEC (12.08 meq /100 g soil) values. [30]

**Table 1.** Selected soil Physico-chemical properties of the experimental site before planting.

Physical properties	Values	References
Soil texture:		
Sand (%)	54.28	
Clay (%)	20.72	
Silt (%)	30	
Textural Class	Sandy clay loam	Rowell (1994)
Chemical properties	Result	Rating
PH (by 1:2.5 soil to H <sub>2</sub> O)	6.15	Slightly acidic
Total Nitrogen (%)	0.14	Moderate
Organic Carbon (%)	0.48	moderate
CEC (cmol (+) kg <sup>-1</sup> )	12.08	low
Available P (mg kg <sup>-1</sup> )	13.08	Low
		London (1991)
		Horneck <i>et al.</i> , (2011)

### 3.2. Influence of Phosphorus Fertilizer Rates and Varieties on Crop Phenology

#### *Days to 50% Flowering and Days to 90% Physiological Maturity*

The results of the Anova analysis indicated that the days to flowering and days to 90% physiological maturity were significantly influenced by phosphorus ( $p < 0.05$ ), although the main effect of variety but not significantly affected by the interaction effect of both factors.

Regarding the main effect of Variety Batu showed the earliest days to flowering (40.6 days) and days to maturity (91.06 days), while variety Hawasa dume showed the longest days to flowering (44.8 days) and days to maturity (94.06 days) (Table 2). Genetic variations may be the cause of these variances in common bean types' days to 50% flowering and days to 90% physiological maturity. Similarly, [18] found a noteworthy difference in the number of days to 50% flowering and days to 90% physiological maturity amongst common bean types, which is consistent with this outcome.

As for the main effect of fertilizer rates, the application of 92 kg P ha<sup>-1</sup> resulted in the earliest days to flowering (40.88 days) and days to maturity (90.66 days), which is statistically equivalent to the application of 69 kg P ha<sup>-1</sup>. In contrast, the control plot showed the longer days to flowering (44.44 days) and days to maturity (97.22 days). With higher rates of P application compared to control, there was a trend toward a decrease in the number of days needed to reach 50% flowering and maturity. The reason for this variance could be the stimulatory impact of phosphorus on growth hormones, which causes common beans to mature and flower early.

Consistent with these results, [25] also observed that early flowering and maturity in common beans were likely brought

about by higher cytokinins production and improved photosynthates and flower formation resulting from the administration of phosphorus fertilizer. Similarly, [31] found that as P rate increases, common bean days to 50% flowering and maturity were somewhat shortened by P treatment.

### 3.3. Influence of Phosphorus Fertilizer Rates and Varieties on Crop Growth Parameters

#### 3.3.1. Plant Height and Total Number of Primary Branches per Plant

Analysis of variance revealed a significant difference ( $P < 0.01$ ) in plant height and number of primary branch among varieties of common beans and rates of phosphorus however, the interaction of both factors was not significant. Regarding variety effect, the tallest mean value of plant height (68.56 cm), and the maximum number of primary branches per plant (3.30) was recorded with Hawasa dume which is statistically at par with Ado variety while the shortest mean value of plant height (37.10cm) and lowest number of primary branches (2.54) was recorded with Batu variety (Table 2). The observed difference in plant height and number of primary branch among the three common bean varieties could be attributed to inherent genotypic differences. This finding is in agreement with [20], who reported the varietal differences in regard to plant height and number of primary branch.

In terms of fertilizer effect P fertilizer application significantly affects plant height. The tallest plant height (56.68cm) and the highest number of primary branches (3.84) was recorded from the application rate of 69 kg P ha<sup>-1</sup>, while the shortest plant height (39.08 cm) and the lowest number of primary branch (2.08) was recorded from control plot.

Higher vegetative growth of the plants under higher P availability is indicated by the rise in plant height and number of main branches in response to the increased P application rate. These results are similar to the findings of [2, 4], who de-

scribed that a significant response of plant height and number of primary branch to P application on common bean cultivars.

**Table 2.** Main effects of variety and phosphorus application rates on days to flowering, days to maturity, plant height and number of primary branch at Yabello district during the 2023 main cropping season.

Varieties	DF	DM	PH (cm)	NPB
Hawasa dume	44.8 <sup>a</sup>	94.06 <sup>a</sup>	68.56 <sup>a</sup>	3.30 <sup>a</sup>
Ado	41.3 <sup>b</sup>	92.4 <sup>b</sup>	41.293 <sup>b</sup>	3.17 <sup>a</sup>
Batu	40.6 <sup>b</sup>	91.06 <sup>b</sup>	37.10 <sup>b</sup>	2.54 <sup>b</sup>
Lsd (0.05)	1.75	1.96	5.49	0.56
P rate (kg/ha)				
0	44.44 <sup>a</sup>	97.22 <sup>a</sup>	39.08 <sup>c</sup>	2.08 <sup>c</sup>
23	42.00 <sup>b</sup>	94.89 <sup>b</sup>	48.48 <sup>b</sup>	2.88 <sup>bc</sup>
46	42.44 <sup>ab</sup>	92.76 <sup>bc</sup>	49.71 <sup>ab</sup>	3.10 <sup>bc</sup>
69	41.55 <sup>b</sup>	92.66 <sup>bc</sup>	56.68 <sup>a</sup>	3.84 <sup>a</sup>
92	40.88 <sup>b</sup>	90.66 <sup>c</sup>	50.95 <sup>a</sup>	3.24 <sup>ab</sup>
Lsd (0.05)	2.27	2.13	6.68	0.73
CV (%)	5.56	2.83	20.46	15.28

Where: NPB = number of primary branches; CV = coefficient of variation; DF = days to flowering; DM = days to maturity; PH = plant height; LSD: least significant variation Ns at the 5% level of significance, there is no significant difference between means within the same factor and column that are followed by the same letter.

### 3.3.2. Total Nodules and Effective Nodules Numbers Per Plant

The results of the analysis of variance showed that the main effects of variety and phosphorus, as well as the interaction effects of both factors, significantly ( $P < 0.01$ ) influenced the number of nodules and effective nodules per plant. The results indicated that the Ado variety had the lowest number of nodules (25.86) and effective nodules (18.66) per plant at no fertilizer application, while the Hawasa dume variety had the highest total nodule numbers (63.73) and effective nodules numbers (50.98) per plant with the application of 69 kg P ha<sup>-1</sup>. (Table 3). This could possibly be because different types of legumes require comparatively large amounts of phosphorus for growth and to enhance leaf area, biomass, yield, nodule number, and nodule bulk. The observed variation in nodule number among varieties under fertilizer treatment may be related to the inherent symbiotic characteristics of the varieties. Similarly, the high nodule number with increased rates of P at the optimum rate may be due to the fact that Legume roots require a comparatively high amount of phosphorus to thrive, which favors the for-

mation of many nodules. This result is consistent with the findings of [15], which reported that phosphorus fertilizer application can have a positive impact on plant growth parameters, especially on Nodules per plants. Similarly, the present result was also consistent with [20], who reported increased nodule initiation on common beans with increased P nutrition.

## 3.4. Influence of Phosphorus Fertilizers and Varieties on Yield and Yield Components

### 3.4.1. Number of Pods per Plant and Number of Seeds Per Pod

An analysis of variance showed that the main effect of variety, P rates, and interactions of both factors were significantly differences ( $P < 0.01$ ) in the number of pods per plant and number of seeds per pod.

The Hawasa dume variety yielded the maximum number of pods per plant (25.33) and seed per pod (4.5) at a P fertilizer rate of 69 kg ha<sup>-1</sup>, while the Batu variety yielded the lowest number of pods per plant (8.86) and seed per pod (1.90) at a P fertilizer rate of 0 kg ha<sup>-1</sup> (Table 3). Furthermore,



the difference in the number of pods and seeds per pods observed due to P rates may be explained by the fact that P enhances the development of the canopy and the pod setting in common beans, encouraging the plants to produce more pods per plant and seed per pods in comparison to the control treatment. The genotypic variation of the variety in producing pods and number of seeds per pod may be connected to these variations in the number of pods per plant and seed per pod among the varieties. This result was in line with other authors' findings that, for a number of crops, including common beans, P treatments, variety, and the interaction of variety and P fertilizer rate all significantly affected the number of pods per plant and seed per pod. [7, 23, 2].

### 3.4.2. Above Ground Dry Biomass Yield, Grain Yield (kg ha<sup>-1</sup>) and Hundred Seed Weight (g)

Above-ground dry biomass, grain yield, and hundred seed weight of common beans were significantly ( $P < 0.01$ ) affected by the main effects of variety, phosphorus rates, and the interaction of both components. The Hawasa dume varie-

ty recorded the highest above-ground dry biomass (5796.83 kg ha<sup>-1</sup>) and grain yield (2777.10) at P rates of 69 kg P ha<sup>-1</sup>, which was in statistical parity with 92 kg P ha<sup>-1</sup>. The Batu variety recorded the highest hundred seed weight (44.13) at 92 kg P ha<sup>-1</sup>. On the other hand, the Ado variety recorded the lowest above-ground dry biomass (3513.46 kg ha<sup>-1</sup>), seed yield (1718.73), and hundred seed weight (26.7) at the lowest phosphorous level of 0 kg ha<sup>-1</sup> (Table 4). The genotypic variations of the varieties may be responsible for the variation in aboveground dry biomass yield, seed yield, and hundred seed weight of the varieties across P levels. The increased availability of P for plant vegetative growth may be the cause of the increase in aboveground biomass yield production and seed yield of common beans with increasing P application rates. The number of branches per plant and leaf area may have grown with an appropriate supply of P, increasing the above-ground biomass production. Other researchers [2, 12] also observed significant increases in biomass production, grain yield, and hundred seed weight in response to P application, which is consistent with these results.

**Table 3.** Mean Total nodules per plant, Effective nodules number per plant, Number of pods per plant and number of seed per pods on three Common bean Varieties as Influenced by the Interaction Effect of P rates and Variety in Yabello District during the 2023 main cropping system.

P rates P kg ha <sup>-1</sup>	TNPP			ENPP		
	Varieties			Varieties		
	Hawasa dume	Ado	Batu	Hawasa dume	Ado	Batu
0	26.66 <sup>g</sup>	25.86 <sup>g</sup>	28.66 <sup>fg</sup>	23.80 <sup>f</sup>	18.66 <sup>h</sup>	22.82 <sup>fg</sup>
23	39.20 <sup>def</sup>	41.4 <sup>cde</sup>	40.73 <sup>de</sup>	29.22 <sup>efg</sup>	37.12 <sup>bcde</sup>	36.3 <sup>cdef</sup>
46	48.66 <sup>bcd</sup>	31.80 <sup>efg</sup>	55.60 <sup>ab</sup>	44.76 <sup>ab</sup>	27.24 <sup>efg</sup>	30.5 <sup>d-g</sup>
69	63.73 <sup>a</sup>	34.80 <sup>efg</sup>	35.00 <sup>efg</sup>	50.98 <sup>a</sup>	28.57 <sup>efg</sup>	49.34 <sup>ab</sup>
92	50.86 <sup>bc</sup>	38.20 <sup>def</sup>	43.0 <sup>cde</sup>	42.90 <sup>ab</sup>	31.22 <sup>defg</sup>	38.6 <sup>bcde</sup>
LSD (0.05)	13.79			11.52		
CV (%)	14.40			12.91		

  

P rates P kg ha <sup>-1</sup>	NPPP			NSPP		
	Varieties			Varieties		
	Hawasa dume	Ado	Batu	Hawasa dume	Ado	Batu
0	9.66 <sup>f</sup>	10.73 <sup>def</sup>	8.86 <sup>ef</sup>	2.20 <sup>c</sup>	2.13 <sup>c</sup>	1.90 <sup>c</sup>
23	18.66 <sup>b</sup>	14.80 <sup>bcd</sup>	16.8 <sup>bc</sup>	3.10 <sup>b</sup>	2.30 <sup>bc</sup>	2.46 <sup>bc</sup>
46	13.53 <sup>cde</sup>	12.26 <sup>def</sup>	11.53 <sup>def</sup>	3.30 <sup>bc</sup>	2.60 <sup>c</sup>	3.03 <sup>b</sup>
69	25.33 <sup>a</sup>	11.80 <sup>def</sup>	12.26 <sup>def</sup>	4.50 <sup>a</sup>	2.70 <sup>bc</sup>	2.73 <sup>b</sup>

P rates P kg ha <sup>-1</sup>	NPPP			NSPP		
	Varieties			Varieties		
	Hawasa dume	Ado	Batu	Hawasa dume	Ado	Batu
92	14.93 <sup>bcd</sup>	12.13 <sup>de</sup>	13.80 <sup>cde</sup>	3.80 <sup>ab</sup>	2.80 <sup>bc</sup>	3.76 <sup>ab</sup>
LSD (0.05)	3.91			1.05		
CV (%)	16.96			11.91		

Whereas NPPP stands for number of pods per plant; NSPP for number of seeds per pod; TNPP for total nodules per plant; ENPP for effective nodules per plant; and Means within the same component and column followed by the same letter are not statistically different at the 5% level of significance (CV = coefficient of variation; LSD = least significant difference).

**Table 4.** Mean Above ground dry biomass yield, Seed yield, and hundred seed weight on three Common bean Varieties as Influenced by the Interaction Effect of P rates and Variety in Yabello District during the 2023 main cropping system.

P rates P kg ha <sup>-1</sup>	AGDBY (kg ha <sup>-1</sup> )			GY (kg ha <sup>-1</sup> )			HSW (g)		
	Varieties			Varieties			Varieties		
	Hawasa dume	Ado	Batu	Hawasa dume	Ado	Batu	Hawasa dume	Ado	Batu
0	3739.1 <sup>f</sup>	3613.46 <sup>cdef</sup>	4164.66 <sup>ef</sup>	1833.9 <sup>d</sup>	2041.36 <sup>cd</sup>	1718.73 <sup>d</sup>	25.7 <sup>g</sup>	26.83 <sup>fg</sup>	27.63 <sup>fg</sup>
23	4267.06 <sup>def</sup>	4022.4 <sup>bcde</sup>	4245.83 <sup>bcde</sup>	2247.3 <sup>cd</sup>	2325.96 <sup>cd</sup>	2168.96 <sup>bcd</sup>	26.53 <sup>efg</sup>	31.16 <sup>d-g</sup>	39.4 <sup>abc</sup>
46	4788.86 <sup>bcde</sup>	4229.13 <sup>b-f</sup>	4686.13 <sup>bcde</sup>	2523.8 <sup>cd</sup>	2311.53 <sup>bc</sup>	2371.16 <sup>bc</sup>	27.4 <sup>efg</sup>	33.1 <sup>def</sup>	41.50 <sup>ab</sup>
69	5796.83 <sup>a</sup>	4994.63 <sup>abc</sup>	4711.30 <sup>bcd</sup>	2777.1 <sup>a</sup>	2490.3 <sup>bc</sup>	2669.63 <sup>ab</sup>	28.16 <sup>efg</sup>	36.56 <sup>bcd</sup>	43.86 <sup>a</sup>
92	5716.26 <sup>a</sup>	4836.53 <sup>bc</sup>	5055.53 <sup>ab</sup>	2721.4 <sup>a</sup>	2525.56 <sup>bc</sup>	2579.96 <sup>bc</sup>	33.26 <sup>cde</sup>	35.26 <sup>bcd</sup>	44.13 <sup>a</sup>
LSD (0.05)	741.8			453.8			6.28		
CV (%)	9.7			11.6			11.21		

Where: AGDBY: above -ground dry biomass yield; GY: grain yield; HSW: hundred seed weight; CV: coefficient of variation; LSD: least significant difference; means within the same factor and column followed by the same letter are not significantly different at the 5% level of significance

### 3.4.3. Harvest Index (%)

The main effect of P fertilizer rate had a significant on the harvest index, whereas the main effect of variety and the interaction of P and variety had no significant effect. (Table 1 in Appendix). The harvest index for the P application rate ranged from 48.14 % to 52.27%. The application of 46 kg P ha<sup>-1</sup> yielded the highest harvest index (52.27%), followed by 23 kg P ha<sup>-1</sup>. Though the lowest result (48.14%) was achieved from 0 kg of P ha<sup>-1</sup>, the maximum harvest index was reported for 46 kg P ha<sup>-1</sup>, statistically comparable with those for 23 kg P ha<sup>-1</sup>, 69 kg P ha<sup>-1</sup>, and 92 kg P ha<sup>-1</sup>. (Table 5). The biological success of partitioning absorbed photosyn-

thates into the harvestable product is shown by the greatest mean harvest index. This finding was consistent with earlier studies by [2] and [7], which found that the application of P alone led to an increase in the harvest index.

**Table 5.** Mean number of Harvest index on three Common bean Varieties as Influenced by the Main Effect of the P Application Rates in Yabello District during the 2023 main cropping system.

varieties	HI (%)
Hawasa dume	51.49
Ado	50.87

varieties	HI (%)
Batu	50.78
LSD (0.05)	ns
P rate (kg/ha)	
0	48.14 <sup>b</sup>
23	52.25 <sup>a</sup>
46	52.27 <sup>a</sup>
69	52.08 <sup>a</sup>
92	50.48 <sup>ab</sup>
LSD (0.05)	3.89
CV (%)	7.89

Where: HI: Harvest index; CV: Coefficient of variation; LSD: Least significant difference; Means within the same factor and column followed by the same letter are not significantly different at the 5% level of significance.

### 3.5. Correlation between Common Bean Yield and Yield Components

The number of pods per plant, the number of seeds per pod, plant height, number of primary branches, and all nodule parameters that is, the number of nodules and the number of effective nodules were positively and significantly ( $P < 0.01$ ) correlated with the grain yield. Among the yield components, grain yield had the strongest correlation with above-ground biomass ( $r = 0.92$ ) and pod per plant ( $r = 0.54$ ), in that order. Above-ground dry biomass showed a strong positive correlation ( $r = 0.44$ ) with plant height and a positive and statistically significant ( $p < 0.01$ ) relationship ( $r = 0.42$ ) with the number of pods per plant and plant height, respectively. But there was also a significant correlation ( $r = 0.65$ ) between plant height and grain yield. The study's findings about the relationship between seed yield and yield-related variables aligned with those of [23, 2], who reported substantial relationships between common bean yield and its constituent yield elements.

**Table 6.** Correlation between Yield and Yield Components of three Common bean varieties in Yabello District during the 2023 main cropping system.

	PH	NPB	TNN	ENN	PPP	NSP	HSW	SY	AGDB
PH									
NPB	0.09 <sup>ns</sup>								
TNN	0.28 <sup>ns</sup>	0.23 <sup>*</sup>							
ENN	0.36 <sup>*</sup>	0.27 <sup>*</sup>	0.95 <sup>***</sup>						
NPP	0.55 <sup>**</sup>	0.33 <sup>**</sup>	0.58 <sup>**</sup>	0.51 <sup>**</sup>					
NSP	0.44 <sup>**</sup>	0.15 <sup>ns</sup>	0.52 <sup>**</sup>	0.44 <sup>**</sup>	0.32 <sup>*</sup>				
HSW	-0.42 <sup>ns</sup>	0.54 <sup>**</sup>	0.10 <sup>ns</sup>	0.15 <sup>ns</sup>	0.05 <sup>ns</sup>	0.12 <sup>ns</sup>			
SY	0.65 <sup>**</sup>	0.33 <sup>**</sup>	0.25 <sup>*</sup>	0.28 <sup>*</sup>	0.54 <sup>**</sup>	0.40 <sup>**</sup>	0.15 <sup>*</sup>		
AGDB	0.44 <sup>**</sup>	0.19 <sup>*</sup>	0.24 <sup>*</sup>	0.24 <sup>*</sup>	0.42 <sup>**</sup>	0.38 <sup>**</sup>	0.10 <sup>ns</sup>	0.92 <sup>**</sup>	

Where: Plant height (PH), number of primary branches (NPB), total number of nodules (TNN), number of effective nodules (ENN), number of pods per plant (NPP), number of seeds per pod (NSP), and above-ground dry biomass (DAGBM). \* Correlation significant at 0.05 level; \*\* Correlation extremely significant at 0.01 level; HSW: Hundred (100) seed weight.

### 3.6. Partial Budget Analysis

The cost-benefit analysis showed that the highest net benefit of (120,856) with an acceptable MRR (1,144.44) was achieved from Hawasa dume variety at 46 kg ha<sup>-1</sup> of P application rate. However, the lowest mean net benefits of (67,842) Birr ha<sup>-1</sup> were obtained from the unfertilized plot with the Batu variety (Table 7). Therefore, on economic grounds, an application rate of Phosphorus fertilizer application at rates 46 for would be

best and most economical for the production of Hawasa dume variety in Yabello district. 'Analysis of the net benefits, total costs that vary and marginal rate of returns are presented in Table 7. Information on costs and benefits of treatments is a prerequisite for adoption of technical innovation by farmers. The study assessed the economic benefits of the treatments to help develop recommendation from the agronomic data. This enhances selection of the right combination of resources by farmers in the study area.

The results in this study indicated that the applications of



phosphorus, resulted in higher net benefits (Table 7). The partial budget analysis was done on the basis of cost of phosphorus and application cost. The partial budget analysis showed that the application of 46 kg ha<sup>-1</sup> of P on Hawasa dume variety produced the highest net benefits. Thus, the highest net benefits of 120,856 Birr ha<sup>-1</sup> with highest marginal rate of return of (1,144.44%) was obtained from application of phosphorus fertilizer at 46kg P ha<sup>-1</sup>. On the other

hand, the control treatments for Hawasa dume, Batu and Ado produced the lowest net benefits (69,356, 77,342.85 and 85,737.12 Birr ha<sup>-1</sup>) respectively. This implies that farmers could be benefited by applying phosphorus at 46kg P ha<sup>-1</sup> this increases common bean yields and thus increase farmers' income. Thus, the application of 46 kg P ha<sup>-1</sup> is profitable and recommended for the farmers in the Yabello district, Borana Zone southern Oromia.

**Table 7.** Partial budget analysis of the effects of phosphorus application rates on common bean varieties in Yabello District during the 2023 main cropping system.

Treatments Varieties	P	Income (ETB ha <sup>-1</sup> )		TVC (ETB ha <sup>-1</sup> )	ΔTVC (ETB ha <sup>-1</sup> )	NB (ETB ha <sup>-1</sup> )	ΔNB (ETB ha <sup>-1</sup> )	MRR (%)
		AGY	TGB					
Hawasa dume	0	1733.9	69356	4000	0	69356	0	D
Hawasa dume	23	2677.1	111084	6350	2350	107084	37728	1605.447
Hawasa dume	46	25000	120856	8500	4500	120856	51500	1144.44
Hawasa dume	69	2023.8	80952	10650	6650	80952	11596	174.3759
Hawasa dume	92	2147.3	85892	12800	8800	85892	16536	187.9091
Ado	0	2041.36	81654.4	5000	1000	85737.12	0	D
Ado	23	2525.56	101022.4	7150	3150	106073.5	20336.4	645.6
Ado	46	2225.96	89038.4	9300	5300	93490.32	7753.2	146.2868
Ado	69	2490.3	99612	11450	7450	104592.6	18855.48	253.0937
Ado	92	2311.53	92461.2	13600	9600	97084.26	11347.14	118.1994
Batu	0	1718.73	80780.31	5000	1000	77342.85	0	D
Batu	23	2669.63	125472.6	7950	3950	120133.4	42790.5	1083.304
Batu	46	2371.16	111444.5	10100	6100	106702.2	29359.35	481.3008
Batu	69	2188.96	102881.1	12250	8250	98503.2	21160.35	256.4891
Batu	92	2379.96	111858.1	14400	10400	107098.2	29755.35	286.1091

P stands for phosphorous, and AGY for adjusted grain yield. ETB stands for Ethiopian Birr per hectare, D for Dominated, TVC for Total Variable Cost, ΔTVC for Change in Total Variable Cost, NB for Net Benefit, and ΔNB for Change in Net Benefit, and MRR for Marginal Rate of return

## 4. Summary and Conclusion

Common bean production in Ethiopia is showing an increasing trend in area and volume from the lowlands to the highlands. It is among the pulse crops that are grown in the Yabello areas most frequently, however, because to the restricted use of better varieties, deteriorating soil fertility, insufficient fertilizer use, severe nutrient depletion, numerous illnesses, and subpar cultural practices, its yield is lower than the regional and national yields. Therefore this experiment was conducted to evaluate the effect of P fertilizer rates

on the, agronomic, nodulation, and yield performances of common bean varieties during the 2023 cropping seasons in Yabello District, Southern Oromia. The experiments were laid out using a randomized complete block design in factorial arrangements with three replications. It consisted of three common bean varieties (Hawasa dume, Ado, and Batu) and five levels of P fertilizer (0, 23, 46, 69, and 92 kg ha<sup>-1</sup>) in the form of TSP. The data obtained were subjected to R statistical software version 4.2. A mean comparison was done using the LSD test at the 5% probability level. The results revealed highly significant ( $P < 0.001$ ) due to the main effect of varieties and P rates on most of the studied parameters, such as phenology, growth, nodulation, and yield components of

common bean varieties, showed significant improvements. On the other hand, the interaction effects of variety and P rates showed a significant variation in total nodule number, effective nodule, number of pods per plant, number of seeds per pod, hundred seed weight, seed yield, and above-ground total dry biomass yield. The highest seed yield (2777.10 kg ha<sup>-1</sup>) was recorded from the interaction effects of the Hawasa dume variety with the supply of P at a rate of 69 kg ha<sup>-1</sup> while the lowest seed yield (1718.73) was recorded from the Batu variety without P application. Additionally, correlation analysis demonstrated a positive and substantial relationship between seed yield and the majority of yield-related factors. The Hawasa dume variety, with 46 kg P ha<sup>-1</sup> application, had the highest net return (120,856 ETB ha<sup>-1</sup>) with an acceptable marginal rate of return (1,144.44%), according to the economic study. In conclusion, Yabello district common bean growers may benefit from using the Hawasa dume variety and applying 46 kg P ha<sup>-1</sup> of P fertilizer in order to maximize output and improve economic return. However, the experiment was conducted for one season at a single location. It is feasible to conduct comparable studies over a larger variety of agro-ecological conditions in order to provide more recommendation.

## Abbreviations

CSA	Central Statistical Agency
CIMMYT	International Maize and Wheat Improvement Center
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
LSD	Least Significance Difference
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural development
MRR	Marginal Rate of Return
OARI	Oromia Agricultural Research Institutes
TSP	Triple Super Phosphate
YPDARC	Yabello Pastoral and Dry Land Agriculture Research Centre

## Conflicts of Interest

The authors declare no conflicts of interest.

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