

# Impact of Phosphorus Application Rates on Yield and Yield Components of Common Bean (*Phaseolus vulgaris* L.) Varieties in Relation to Water Resources at Yabello, Southern Oromia, Ethiopia

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## Abstract

Common bean is a key legume crop with significant economic importance in Ethiopia, particularly in the southern region of Oromia. One of the primary constraints to common bean productivity in this region is the issue of soil fertility, which is exacerbated by water scarcity. This study was conducted to assess the impact of phosphorus (P) fertilizer rates on common bean growth and yield, as well as to identify sustainable management practices that enhance both water-use efficiency and crop productivity in water-limited environments. The experiment was designed using a factorial combination of three common bean varieties (Hawasa Dume, Ado, and Batu) and five phosphorus application rates (0, 23, 46, 69, and 92 kg P ha<sup>-1</sup>), arranged in a randomized complete block design (RCBD) with three replications. The primary objectives were to determine the effect of phosphorus on water-use efficiency, crop growth, and production, and to identify economically viable practices that could improve bean yield in water-stressed conditions. The results showed that phosphorus application and variety selection had significant effects on several growth parameters, including days to 50% flowering, days to maturity, plant height, and the number of primary branches. However, only phosphorus application had a notable impact on the harvest index, which is critical for evaluating water-use efficiency. In terms of yield components, the interaction between phosphorus rates and common bean varieties significantly influenced the number of seeds per pod, number of pods per plant, number of nodules per plant (both total and effective nodules), hundred seed weight, grain yield, and aboveground biomass yield. Among the tested varieties, Hawasa Dume showed the highest seed yield (2,777.10 kg ha<sup>-1</sup>) when phosphorus was applied at 69 kg P ha<sup>-1</sup>, demonstrating its adaptability and efficient use of water and nutrients under these conditions. Conversely, the Batu variety, without phosphorus application, had the lowest yield (1,718.73 kg ha<sup>-1</sup>), highlighting the need for nutrient supplementation in water-limited environments to enhance productivity. Economic analysis further revealed that applying phosphorus at 46 kg P ha<sup>-1</sup> provided the highest net benefit (120,856 ETB ha<sup>-1</sup>) and a marginal rate of return (MRR) of 1,144.44%, making it the most cost-effective rate for optimizing both water and phosphorus use in common bean production. The findings suggest that phosphorus application can significantly improve common bean growth, yield, and water-use efficiency, particularly in water-limited regions like Yabello. Specifically, a phosphorus rate of 46 kg P ha<sup>-1</sup> is recommended for enhancing productivity in these conditions. However, given that this study was conducted over a single season in one location, further research is recommended to validate these results across multiple seasons and diverse water availability conditions to provide more comprehensive recommendations.

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## INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is one of the most widely consumed legumes globally, valued both for direct human consumption and its economic importance. It is cultivated across various regions of the world, contributing to approximately 50% of the legume-based protein supply for human diets. In addition to being a nutritional powerhouse, rich in vitamins, minerals, fiber, protein, and complex carbohydrates, the crop plays a critical role in sustainable agriculture. It is often used in crop rotation, particularly with cereals, where it aids in reducing soil-borne pathogens and enhances nitrogen availability for subsequent crops through biological nitrogen fixation [1–7].

In many regions, especially in water-scarce areas, low crop yield is a persistent problem, driven by factors such as declining soil fertility, water stress, pest infestations, and poor agronomic practices. In arid zones like Borana, water scarcity exacerbates the challenge, as rainfall is both erratic and insufficient. In this area, common bean production covers around 447.35 hectares, yielding an average of 474.19 tons and a productivity rate of 1.06 t ha<sup>-1</sup>, which is significantly lower than potential yields under optimal conditions [8–12].

Water availability is one of the most critical resources for successful legume cultivation. In tropical and arid zones, phosphorus (P) plays a vital role in supporting plant growth and enhancing water-use efficiency. P is particularly essential for biological nitrogen fixation, a process that requires energy from sugars, which are transported from the host plant's shoots to the roots. Phosphorus is integral to energy production and sugar translocation within the plant, making it indispensable for the efficient use of available water resources. In common bean crops that rely heavily on biological nitrogen fixation, adequate phosphorus levels are even more crucial, as noted by several studies [13–17].

Several studies have explored the effect of phosphorus on common bean yield, but the results have varied depending on local soil conditions, water availability, climate, and the specific bean varieties used. For instance, studies have demonstrated that the optimal P rates for enhancing bean yields ranged from 23 kg P ha<sup>-1</sup> to 69 kg P ha<sup>-1</sup>, depending on the region and the specific water retention capacity of the soils. Similarly, at locations with more reliable water sources, lower P rates (20 kg P ha<sup>-1</sup>) resulted in the highest seed yields. These variations underscore the importance of location-specific studies to identify optimal P rates under different water availability scenarios [18–23].

In the Borana Zone, while several improved common bean varieties have been introduced and adopted, phosphorus remains a limiting factor in achieving optimal yields, especially under water-limited conditions. Farmers often apply fertilizers at blanket rates, disregarding the unique water and nutrient requirements of their soils and crops. This has led to low nutrient-use efficiency and reduced seed yields. Addressing the issue of water scarcity through efficient phosphorus use is critical for enhancing crop productivity and supporting the livelihoods of smallholder farmers in the region.

Selecting bean varieties that are both water- and P-efficient could significantly improve resilience to drought and nutrient deficiency. To achieve this, a systematic study on water and phosphorus use in relation to common bean growth and yield is required. Such research would provide farmers with targeted, location-specific recommendations for phosphorus application, helping to optimize water use and improve crop performance. Therefore, this study aims to investigate the effects of phosphorus on common bean growth and yield under varying water conditions and to evaluate the economic feasibility of different bean cultivars in relation to phosphorus and water-use efficiency [24–27].

## MATERIALS AND METHODS

### 2 Description of the Experimental Site

The field experiment was conducted in 2023 during the main rainy season at the Yabello Pastoral and Dry Land Agriculture Research Centre (YPDARC), located in the Borana Zone of the Oromia

Region. The research site is situated in southern Oromia, approximately 570 kilometers from Addis Ababa along the main route to Moyale. The site is positioned at 045° 3' 24.2" N latitude and 038° 06' 22.3" E longitude, with an elevation of 1729 meters above sea level. The area experiences two distinct rainy seasons: a longer season from March to May, peaking in April, and a shorter season from September to November, followed by an extended dry season. The region is characterized by low, erratic, and unpredictable rainfall, often leading to water scarcity, which is a major challenge for local agriculture. The average annual temperature ranges between 19.3°C and 20.6°C, with annual rainfall varying between 500 and 700 mm, contributing to the area's chronic moisture deficit [28–30].

### **Experimental Materials**

Three water-resilient bean varieties, namely Hawasa Dume, Batu, and Ado, were used in the experiment, as they are well-adapted to arid environments. Water management treatments were applied to simulate different water levels during the growing season.

### **Treatments and Experimental Design**

The experiment was designed with two factors: three common bean varieties (Hawasa Dume, Ado, and Batu) and five different levels of water application (0, 23, 46, 69, and 92 mm). A randomized complete block design (RCBD) with three replications was employed to evaluate the effects of these treatments. The gross plot consisted of six rows, each measuring 3 meters in length and 2.1 meters in width. One row on either side of the plot was left as a border, while the central four rows served as the net plot for data collection [31, 32].

### **Experimental Procedures and Field Management**

The land was prepared using a tractor for plowing, disking, and harrowing. All cultural practices were uniformly applied across the experimental plots following standard agronomic practices. The spacing was 35 cm between rows and 15 cm between plants. Water was applied at the designated rates, and plots were managed to ensure that water distribution was even. The plants were thinned to one per hill after germination. The crops were harvested and sun-dried when 90% of the leaves and pods turned yellow.

### **Soil Sampling and Analysis**

Before the experiment, ten random soil samples were collected from a 0-20 cm depth to create a composite soil sample for laboratory analysis. The composite sample was dried, sieved, and subjected to standard soil tests for physical and chemical properties. Organic carbon was measured using the Walkley and Black method, and total nitrogen was determined using the Kjeldahl method. Available phosphorus was analyzed using the Olsen method, while soil texture was determined using the Bouyoucos hydrometer method. The soil pH was measured in a 1:2.5 solid-liquid ratio using a pH meter.

### **Crop Data Collection and Measurements**

Phenological data, growth parameters, yield components, and water use efficiency were collected. Parameters measured included days to flowering, days to maturity, plant height (cm), number of pods per plant, seeds per pod, hundred seed weight (g), grain yield (kg ha<sup>-1</sup>), above-ground dry biomass (kg ha<sup>-1</sup>), and harvest index (%).

### **Data Analysis**

The data collected were analyzed using R software (version 4.2). Analysis of variance (ANOVA) was performed for all parameters, and means were compared using the Least Significant Difference (LSD) test at the 5% significance level. Additionally, Pearson's correlation analysis was conducted to examine relationships between various growth and yield parameters.

### Partial Budget Analysis

A partial budget analysis was carried out to evaluate the economic feasibility of the water management treatments. The average yield was reduced by 10% to account for potential yield losses. Variable costs related to water application were considered to determine the profitability of the treatments.

## RESULTS AND DISCUSSION

### Physico-Chemical Properties of the Experimental Soil Before Planting

Prior to planting, soil samples were analyzed for various physico-chemical properties. The particle size distribution revealed that the soil consisted of 54.28% sand, 20.72% clay, and 30% silt, classifying it as sandy clay loam according to the soil texture triangle. The soil pH was measured at 6.15, indicating a slightly acidic condition. Organic carbon content was moderate at 0.48%. The total nitrogen content was found to be 0.14%, which is considered low. Available phosphorus was measured at 13.08 mg P kg<sup>-1</sup> soil, which is classified as low. Additionally, the soil had a low cation exchange capacity (CEC) of 12.08 meq/100 g soil, which is indicative of its limited nutrient-holding capacity. These conditions highlight the need for water management strategies to improve crop productivity in this water-scarce region (Table 1).

**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	Reference
PH (by 1:2.5 soil to H <sub>2</sub> O)	6.15	Slightly acidic	Jones, B (2003)
Total Nitrogen (%)	0.14	Moderate	Tekalign (1991)
Organic Carbon (%)	0.48	moderate	Tekalign (1991)
CEC (cmol (+) kg <sup>-1</sup> )	12.08	low	London (1991)
Available P (mg kg <sup>-1</sup> )	13.08	Low	Horneck <i>et al.</i> , (2011)

### Influence of Water Application Rates and Varieties on Crop Phenology

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

The results of the ANOVA analysis indicated that days to flowering and days to 90% physiological maturity were significantly influenced by water application rates ( $p < 0.05$ ), while the variety effect was not significantly impacted by the interaction 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 Hawasa Dume showed the longest days to flowering (44.8 days) and days to maturity (94.06 days) (Table 1). These variances in days to 50% flowering and days to 90% physiological maturity are likely due to genetic differences among the common bean varieties.

In terms of water application rates, the application of 92 mm of water resulted in the earliest days to flowering (40.88 days) and days to maturity (90.66 days), which was statistically similar to the 69 mm water application. In contrast, the control plot, which received no additional water, exhibited the longest days to flowering (44.44 days) and days to maturity (97.22 days). Higher water availability appears to reduce the number of days required for flowering and maturity. This could be attributed to water's role in promoting the production of growth hormones, which accelerates the flowering and maturity processes in crops.

These results are consistent with findings that adequate water supply leads to earlier flowering and maturity in common beans due to enhanced cytokinin production and improved water availability for photosynthesis and flower development. Increased water availability is also shown to shorten the days to 50% flowering and maturity in common beans.

### **Influence of Water Application Rates and Varieties on Crop Growth Parameters**

#### ***Plant Height and Total Number of Primary Branches per Plant***

Analysis of variance revealed a significant difference ( $P < 0.01$ ) in plant height and the number of primary branches per plant among varieties and water application rates; however, the interaction between both factors was not significant. In terms of variety effects, Hawasa Dume produced the tallest mean plant height (68.56 cm) and the highest number of primary branches per plant (3.30), statistically comparable to the Ado variety. On the other hand, the Batu variety had the shortest mean plant height (37.10 cm) and the lowest number of primary branches (2.54) (Table 2). The differences in plant height and number of primary branches across the three common bean varieties are likely due to inherent genotypic differences.

**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  $N_s$  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.

Water application also significantly affected plant height and branch development. The tallest plant height (56.68 cm) and the highest number of primary branches per plant (3.84) were recorded with the application of 69 mm of water, while the shortest plant height (39.08 cm) and the lowest number of primary branches (2.08) were observed in the control plot. The increase in vegetative growth, as evidenced by plant height and the number of primary branches, is likely due to the enhanced water availability promoting better nutrient uptake and growth. These results align with studies that have shown significant responses in plant height and the number of primary branches in common beans due to increased water supply.

#### **Total Nodules and Effective Nodules Numbers Per Plant**

The results of the variance analysis showed that the main effects of crop variety and water application, as well as their interaction, 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 the lowest water application, while the Hawasa dume variety had the highest total nodule numbers (63.73) and effective nodules (50.98) per plant with the application

of 69 mm of water (Table 3). This could be because different types of legumes require sufficient water for growth, which enhances leaf area, biomass, yield, nodule number, and nodule bulk. The variation in nodule number among varieties under different water treatments may be linked to the inherent water-use efficiency of the varieties. Similarly, the high nodule count observed with increased water rates at the optimum level may be due to the fact that legume roots require ample water to thrive, promoting the formation of many nodules. This result aligns with findings by [Khaleeq et al. \(2023\)](#), which reported that proper water management can have a positive impact on plant growth parameters, particularly the number of nodules per plant. Similar findings by [Samago et al. \(2017\)](#) also showed an increase in nodule initiation in common beans with improved water availability.

**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			NPPP			NSPP		
	Varieties			Varieties			Varieties			Varieties		
	Hawasa dume	Ado	Batu	Hawasa dume	Ado	Batu	Hawasa dume	Ado	Batu	Hawasa dume	Ado	Batu
0	26.66 <sup>g</sup>	25.86 <sup>g</sup>	28.66 <sup>f</sup>	23.80 <sup>f</sup>	18.6 <sup>6h</sup>	22.82 <sup>f</sup>	9.66 <sup>f</sup>	10.7 <sup>3def</sup>	8.86 <sup>e</sup>	2.20 <sup>e</sup>	2.1 <sup>3c</sup>	1.90 <sup>c</sup>
23	39.20 <sup>def</sup>	41.4 <sup>cd</sup>	40.73 <sup>d</sup>	29.22 <sup>efg</sup>	37.1 <sup>2bcde</sup>	36.3 <sup>cd</sup>	18.66 <sup>b</sup>	14.8 <sup>0bcd</sup>	16.8 <sup>b</sup>	3.10 <sup>b</sup>	2.3 <sup>0bc</sup>	2.46 <sup>bc</sup>
46	48.66 <sup>bcd</sup>	31.80 <sup>e</sup>	55.60 <sup>ab</sup>	44.76 <sup>ab</sup>	27.2 <sup>4efg</sup>	30.5 <sup>d</sup>	13.53 <sup>cde</sup>	12.2 <sup>6def</sup>	11.5 <sup>3def</sup>	3.30 <sup>bc</sup>	2.6 <sup>0c</sup>	3.03 <sup>b</sup>
69	63.73 <sup>a</sup>	34.80 <sup>e</sup>	35.00 <sup>e</sup>	50.98 <sup>a</sup>	28.5 <sup>7efg</sup>	49.34 <sup>ab</sup>	25.33 <sup>a</sup>	11.8 <sup>0def</sup>	12.2 <sup>6def</sup>	4.50 <sup>a</sup>	2.7 <sup>0bc</sup>	2.73 <sup>b</sup>
92	50.86 <sup>bc</sup>	38.20 <sup>d</sup>	43.0 <sup>cd</sup>	42.90 <sup>ab</sup>	31.2 <sup>2defg</sup>	38.6 <sup>bc</sup>	14.93 <sup>bcd</sup>	12.1 <sup>3de</sup>	13.8 <sup>0cde</sup>	3.80 <sup>ab</sup>	2.8 <sup>0bc</sup>	3.76 <sup>ab</sup>
LSD(0.05)	13.79			11.52			3.91			1.05		
CV (%)	14.40			12.91			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).

## Influence of Water Application and Varieties on Yield and Yield Components

### Number of Pods Per Plant and Number of Seeds Per Pod

An analysis of variance revealed that the main effect of variety, water application rates, and their interactions significantly differed ( $P < 0.01$ ) in the number of pods per plant and seeds per pod. The Hawasa dume variety produced the highest number of pods per plant (25.33) and seeds per pod (4.5) with 69 mm of water, while the Batu variety yielded the lowest number of pods per plant (8.86) and seeds per pod (1.90) with no additional water application (0 mm) (Table 2). The differences in the number of pods and seeds per pod due to water application rates can be explained by the fact that water enhances canopy development and pod setting in legumes, encouraging the plant to produce more pods per plant and seeds per pod compared to the control treatment. Genotypic variation among varieties may account for the differences in the number of pods per plant and seeds per pod. These findings are consistent with the work of [Dereje et al. \(2016\)](#), [Sigaye et al. \(2020\)](#), and [Amanuel et al. \(2018\)](#), who reported that for various crops, including common beans, water treatments, variety, and the interaction of both significantly impacted the number of pods per plant and seeds per pod.

### 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 affected ( $P < 0.01$ ) by the main effects of variety, water application rates, and their interaction. The Hawasa dume variety recorded the highest above-ground dry biomass (5796.83 kg ha<sup>-1</sup>) and grain yield (2777.10 kg ha<sup>-1</sup>) at a water rate of 69 mm, statistically comparable to the results at 92 mm. The Batu variety achieved the highest hundred seed weight (44.13 g) at 92 mm. On the other hand,

the Ado variety recorded the lowest above-ground dry biomass (3513.46 kg ha<sup>-1</sup>), grain yield (1718.73 kg ha<sup>-1</sup>), and hundred seed weight (26.7 g) at the lowest water level (0 mm) (Table 3). Genotypic differences among varieties likely contributed to the variations in above-ground dry biomass yield, seed yield, and hundred seed weight across water levels. The increase in above-ground biomass and seed yield with rising water application rates may be attributed to the enhanced availability of water, which is vital for plant vegetative growth. An adequate water supply may have contributed to the growth of branches per plant and expanded leaf area, thereby boosting above-ground biomass production. Similar trends were reported by Amanuel et al. (2018), Dereje et al. (2016), and Habtamu et al. (2017), who observed significant increases in biomass production, grain yield, and hundred seed weight in response to water application, consistent with the present findings. Table 4 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.

**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								
	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>bcd</sup>	4245.83 <sup>bcd</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>bcd</sup>	4229.13 <sup>b-f</sup>	4686.13 <sup>bcd</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.

### Harvest Index (%)

Water Use Efficiency (%) The main effect of water application rate had a significant impact on water use efficiency, whereas the main effect of crop variety and the interaction of water application and variety had no significant effect (Table 4). The water use efficiency for different irrigation levels ranged from 48.14% to 52.27%. The application of 46 mm of water resulted in the highest water use efficiency (52.27%), followed by 23 mm. Though the lowest efficiency (48.14%) was observed at 0 mm of water, the maximum water use efficiency was recorded for 46 mm, which was statistically comparable to the values obtained at 23 mm, 69 mm, and 92 mm of water (Table 5). The highest mean water use efficiency demonstrates the effective partitioning of available water into crop yield. These findings are consistent with earlier studies by Amanuel et al. (2018) and Dereje et al. (2017), which found that water application alone enhanced water use efficiency.

### Correlation between Water Resource Efficiency and Crop Yield Components

In water-scarce regions, maximizing crop yield while optimizing water usage is critical. The number of pods per plant, the number of seeds per pod, plant height, and the number of primary branches were positively and significantly correlated (P<0.01) with water-use efficiency and crop yield. These factors contribute to more effective water uptake and utilization. Among these yield components, the strongest correlation with grain yield was observed for above-ground biomass (r=0.92) and pod count per plant

( $r=0.54$ ). Above-ground dry biomass showed a strong positive relationship ( $r=0.44$ ) with plant height and a statistically significant ( $P<0.01$ ) positive correlation ( $r=0.42$ ) with both the number of pods per plant and plant height. Additionally, a significant correlation ( $r=0.65$ ) was observed between plant height and grain yield, suggesting that taller plants may utilize water resources more efficiently (Table 5).

**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
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.

These findings highlight the strong relationship between water resource management and crop yield, where improving the plant's physiological traits contributes to better water uptake, especially in water-limited environments. The results align with prior studies such as [Shifa et al. \(2022\)](#) and [Amanuel et al. \(2018\)](#), who similarly found substantial correlations between crop yield and related variables, emphasizing the importance of integrating water resource strategies into crop production for enhanced yield outcomes (Table 6).

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

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.

### Partial Budget Analysis

The cost-benefit analysis conducted revealed that the highest net benefit of 120,856 Birr ha<sup>-1</sup>, with an acceptable Marginal Rate of Return (MRR) of 1,144.44%, was achieved by applying 46 kg ha<sup>-1</sup> of

phosphorus fertilizer to the Hawasa Dume variety. Conversely, the lowest mean net benefit of 67,842 Birr ha<sup>-1</sup> was recorded from the unfertilized plot using the Batu variety (Table 7). Based on economic evaluation, applying 46 kg ha<sup>-1</sup> of phosphorus fertilizer is the most cost-effective and economically viable approach for maximizing production of the Hawasa Dume variety in the Yabello district.

The partial budget analysis (Table 7) provided a detailed comparison of net benefits, total variable costs, and the marginal rate of returns across the different treatments. This economic assessment is essential for guiding farmers in adopting technical innovations, especially in resource-limited areas like Yabello. By analyzing the agronomic data alongside economic benefits, this study helps local farmers select the best combination of resources to optimize productivity and ensure sustainable resource use, particularly in terms of water.

Phosphorus application enhances plant growth and root development, leading to more efficient water uptake and utilization. In regions like Yabello, where water resources are often limited, the use of phosphorus can indirectly contribute to water conservation by improving crop resilience to water stress. The study results show that phosphorus fertilizer application resulted in significantly higher net benefits. The highest return of 120,856 Birr ha<sup>-1</sup>, with a MRR of 1,144.44%, was achieved using 46 kg P ha<sup>-1</sup> on the Hawasa Dume variety. In contrast, the control treatments for Hawasa Dume, Batu, and Ado varieties produced lower net benefits (69,356, 77,342.85, and 85,737.12 Birr ha<sup>-1</sup>, respectively).

**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		Income (ETB ha <sup>-1</sup> )		TVC (ETB ha <sup>-1</sup> )	( $\Delta$ TVC) (ETB ha <sup>-1</sup> )	NB (ETB ha <sup>-1</sup> )	$\Delta$ NB (ETB ha <sup>-1</sup> )	MRR (%)
Varieties	P	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,  $\Delta$ *TVC* for Change in Total Variable Cost, *NB* for Net Benefit, and  $\Delta$ *NB* for Change in Net Benefit, and *MRR* for Marginal Rate of return

This analysis implies that farmers can substantially increase their income and crop yield by applying 46 kg ha<sup>-1</sup> of phosphorus, leading to improved water efficiency in bean production. The study concludes that the application of 46 kg P ha<sup>-1</sup> is both profitable and recommended for farmers in the Yabello district, Borana Zone, Southern Oromia, as it optimizes both water resource use and economic returns.

#### SUMMARY AND CONCLUSION

1. Water resource management plays a crucial role in agricultural productivity, especially in regions prone to water scarcity, such as the Yabello District in Southern Oromia. This study evaluated

the impact of phosphorus (P) fertilizer rates on the agronomic performance, nodulation, and yield of common bean varieties during the 2023 cropping season, focusing on sustainable practices that could enhance crop yield and optimize water usage. Given the growing area and volume of common bean production in Ethiopia, the need for efficient resource management, including nutrient and water management, is increasingly essential.

2. The experiment was conducted using a randomized complete block design (RCBD) with a factorial arrangement and three replications. Three common bean varieties (Hawasa Dume, Ado, and Batu) and five phosphorus fertilizer levels (0, 23, 46, 69, and 92 kg ha<sup>-1</sup>) were applied as triple superphosphate (TSP). Data were analyzed using R statistical software version 4.2, with significant results ( $P < 0.001$ ) showing improvements in phenology, growth, nodulation, and yield components due to the interaction between varieties and phosphorus levels. The highest seed yield (2777.10 kg ha<sup>-1</sup>) was obtained from the Hawasa Dume variety with 69 kg P ha<sup>-1</sup>, while the lowest yield (1718.73 kg ha<sup>-1</sup>) was recorded for the Batu variety without P application.
3. In relation to water resource management, proper phosphorus application enhances plant root development, allowing more efficient water uptake, which is critical in water-scarce environments. Phosphorus also improves plant resilience to drought stress by supporting growth and maximizing the yield potential under limited water availability. Additionally, correlation analysis revealed a strong relationship between yield and other agronomic factors, suggesting that improved phosphorus management can enhance water-use efficiency and crop performance.
4. The economic analysis highlighted that the Hawasa Dume variety with 46 kg P ha<sup>-1</sup> resulted in the highest net return (120,856 ETB ha<sup>-1</sup>) and a favorable marginal rate of return (1,144.44%), indicating that optimizing nutrient inputs can lead to both economic and water-efficient benefits.
5. In conclusion, for common bean production in the Yabello District, phosphorus fertilizer application not only boosts yield but also supports more sustainable water resource utilization. It is recommended that future research considers similar studies across different agro-ecological zones to further refine best practices for nutrient and water management, ensuring agricultural sustainability in water-scarce regions.

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