



**EFFECTS OF INTEGRATED USE OF *RHIZOBIUM*, VERMICOMPOST,
AND PHOSPHORUS FERTILIZER ON YIELD AND YIELD
COMPONENTS OF COMMON BEANS (*PHASEOLUS VULGARIS* L.)
AND ON SELECTED SOIL PROPERTIES IN WULBAREG DISTRICT,
SILTE ZONE, CENTRAL ETHIOPIA**

MSc THESIS

ZEYNEBA MOHAMMED YIMER

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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ZEYNEBA MOHAMMED YIMER

MAJOR ADVISOR: SHIMELIS GIZACHEW (Ph.D.)

CO-ADVISOR: ALEMAYEHU KIFLU (Ph.D.)

**A THESIS SUBMITTED TO THE SCHOOL OF PLANT AND HORTICULTURAL
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DEDICATION

I dedicate this thesis manuscript to my husband, Seid Mohamed and my family specially my mother Yebirgual Legesse and my father Mohammed Yimer.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this thesis. Any scholarly matter that is included in the thesis has been given recognition through citation. Solemnly declare that this thesis has not been submitted to any other institutions anywhere for the award of any academic degree, diploma or certificate.

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ACRONYMS AND ABBREVIATIONS

Ndfa	Nitrogen Derived From the Athmosphere
ADF	Africa Development Fund
ANOVA	Analysis of Variance
BNF	Biological Nitrogen Fixation
CEC	Catoin Exchange Capacity
CSA	Central Statistical Agency
FAO	Food and Agricultural Organization
GDP	Gross domestic product
GLM	General Linear Model
HI	Harvest Index
K	Potassium
LSD	Least Significant Difference
N	Nitrogen
P	Phosphorus
RCBD	Randomized Complete Block Design
Rh	Rhizobia
SAS	Stastical Analysis System
SNNPR	Southern Nations, Nationalities and People's Region

TND	Total Nitrogen Difference
TSP	Triple Super Phosphate
VC	Vermicompost

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Effects of Integrated Use of Rhizobium, Vermicompost, and Phosphorus Fertilizer on Yield and Yield Components of Common Beans (*Phaseolus Vulgaris* L.) and on Selected Soil Properties in Wulbareg District, Silte Zone, Central Ethiopia

ABSTRACT

Common bean (*Phaseolus vulgaris* L.) Is an important grain legume in Ethiopia. However, the national average yield is very low due to a number of abiotic and biotic stresses, soil fertility depletion, fertilizer application without soil test, and poor crop response to fertilization. Crop specific and soil test based fertilizer recommendations are necessary for sustainable crop production. Therefore, a field experiment was conducted at Wulbareg district to study the effect of integrated use of Rhizobium inoculation, vermicompost, and phosphorus fertilizer on yield and yield components of common bean and on selected soil properties during the 2022 main cropping season. A factorial combination of three phosphorus rates (0, 20, 40 kg P ha⁻¹), three vermicompost rates (0, 4, 8 ton ha⁻¹) and 2 levels of Rhizobium inoculation were laid out in randomized complete block design (RCBD) with three replications. Analysis of baseline soil samples showed that the soil of the experimental area is loam in texture, very strongly acidic in reaction, low in organic carbon, low in total nitrogen, low in available P and high in CEC. The analysis of variance showed that the application of P, VC, Rh inoculation and their interaction significantly ($p < 0.05$) increased most yield and yield parameters of the common bean compared to the control treatment. The highest grain yield (3487.65 kg ha⁻¹) was recorded from 40 kg P ha⁻¹ and 4 t ha⁻¹ VC followed by 40 kg P ha⁻¹ and 8 t ha⁻¹ VC (3395.06 kg ha⁻¹), whereas the lowest grain yield (2098.7 kg ha⁻¹) was recorded from the control. Integrated application of biofertilizer, organic and mineral fertilizers showed a significant influence on BNF. The highest fixed nitrogen (54.42 kg ha⁻¹) and %Ndfa (52.42%) was obtained from the application of phosphorus 20 kg P ha⁻¹, 8 t ha⁻¹ vermicompost and rhizobia inoculation whereas the lowest was (16.12 kg ha⁻¹) and (24.66%) from the control respectively. Most selected soil properties were influenced by the main effect of P, Rh, VC and by their interaction. Bulk density of soil, pH, Organic carbon, total nitrogen, phosphorus and CEC was increased from (1.3 kg cm⁻³) to (1.1 kg cm⁻³), (5.38) to (5.45), (0.97%) to (2.91%), (0.08%) to (0.25%), (6.03 mg kg⁻¹) to (13.88 mg kg⁻¹) and (40 cmol⁽⁺⁾ kg⁻¹) to (44.5 cmol⁽⁺⁾ kg⁻¹) respectively when compared to soil properties before planting. Soil moisture content was affected significantly by VC, PxVC, RhXVC and PXVCXRh which confirm VC effect on moisture content of the soil. Therefore, the result verified that using integrated phosphorus (40 kg ha⁻¹), vermicompost (8 t ha⁻¹) and rhizobium inoculation is recommended in the area of wulbareg district to improve the fertility of the soil and the productivity of the common bean.

Keywords: Common Bean, Integrated, BNF, Grain-Yield, Soil Properties.

1. INTRODUCTION

Agriculture is essential for feeding the world's population and is the main driver of Ethiopia's economic development (FAO, 2020). However increasing the sustainability of soil productivity and the nutrient level base that agriculture depends on is a challenge for developing nations (Lishan *et al.*, 2023). The agricultural industry in Ethiopia employs over 79% of the labor force, generates 79% of the country's foreign revenues, and accounts for 34.1% of the country's GDP. It also serves as the main source of capital and raw materials for market and investment (FAO, 2020). (ADF 2002) reports that smallholder farms in the highlands of Ethiopia provide approximately 95% of the country's agricultural output. These farms are used for subsistence. However, as a result of growing population pressure, the amount of land holding per household dropped, leaving little output to meet specific household consumption needs. Increasing family-level agricultural output is necessary to attain food security (Cholo *et al.*, 2023).

Common bean (*Phaseolus Vulagris* L) is a widely cultivated grain legume that is also referred to as the haricot bean, kidney bean, dry bean, and field bean. This crop, which is annual and a member of the Fabaceae family (Laekemariam and Worku, 2013), is commonly grown on marginal soils at high altitudes and can be produced as a single crop or in intercropping with maize (Aserse *et al.*, 2012). It's considered one of the world's most significant legumes in parts of Latin America and Eastern Africa. This plant accounts for 32% of the energy intake and 65% of the total protein consumed.

Furthermore, the production of beans, a vital crop in developing nations, is estimated to have reached 26 million metric tons worldwide in 2016 (Turan *et al.*, 2019).

Additionally, it is a premium grain legume with a high protein content, pleasing flavor, and large market demand (Laekemariam and Worku, 2013).

It is the most significant since production is concentrated on small-holder farms, which typically have average yields of less than 1 ton ha⁻¹ and where nitrogen (N) fertilizer use is limited (Dela *et al.*, 2023). Due to its long history of cultivation as a field crop, it is essential to Ethiopian cooking and is the most significant food legume produced in the country (Cholo *et al.*, 2023). Most production of common bean in the country is from Oromia (43%), Amhara (25%), and Southern Nations Nationalities and Peoples regions (29%) (Miruts, 2022).

Rhizobia are a class of bacteria that live in symbiotic relationships with legumes, allowing them to fix atmospheric nitrogen (Naseer *et al.*, 2019). It multiplies by taking nutrients from the host plant and forms symbiotic organs called nodules on the roots of its host. They then provide the nitrogen resources created by biological nitrogen fixation to their host plants (Fujita *et al.* 2014). Similarly, (Naseer *et al.*, 2019) reported that Rhizobia symbiosis causes nodules to grow on the host plant's stems or roots. biological N fixation is the most common N fixation process. Globally, an estimated 193 million tons N per year is fixed through biological N fixation (Miyamoto *et al.*, 2008). It is therefore thought that rhizobia that are effective at inoculating legumes can boost crop yields without compromising soil quality. Additionally, it is supposedly an environmentally friendly method for enhancing N fixation, which increases common bean shoot growth, pod count, and grain yield (Siczek and Lipiec, 2016).

Phosphorus is the most significant element for appropriate grain production next to nitrogen (Brady and Weil, 2002).

Early in a plant's life, a sufficient supply of P is crucial for the development of its reproductive organs. Fruit and seeds contain large amounts of P, which is thought to be necessary for the formation of seeds (Havlin, *et al.*, 1999). A good supply of P is associated with increased root growth. P is also related with early maturity of crops, mainly grain crops. When certain crops receive enough P nutrition, their quality improves and their resistance to disease rises in specific fruit, vegetable, grain, and fodder crops (Gidago *et al.*, 2011). The biomass construction of micronutrients, the metabolic process of energy transfer, signal transduction, macromolecular biosynthesis, photosynthesis and respiration chain reactions and nitrogen (N) fixation resulted from contribution of Phosphorus (Hordofa Sigaye *et al.*, 2020). P-deficient plants grow slowly and typically have a low shoot/root dry matter ratio. Plants with a P deficit exhibit suppressed fruit and seed formation and quality (Mengel and Kirkby, 1987). Also reduced nodulation and reduced plant vigor are observed in beans grown in P-deficient soils (Amijee and Giller, 1998).

Vermicompost has the potential to be beneficial for the environment, the economy, and the soil ecology. When chemical fertilizers are used continuously, there are risks to human health and the environment, such as nitrate leaching that contaminates surface and ground water (Eswaran and Mariselvi, 2016). The primary factors that promote plant growth may be the biological characteristics of the vermicompost, the plants that are used, and the cultivation conditions. Applying vermicompost to the soil would increase humus levels, which would recover the soil's physical, chemical, and biological characteristics and water-holding capacity (Singh *et al.*, 2011). The hypothesis of this study is the application of rhizobia, phosphorus and vermicompost significantly influence the growth, yield, and yield components of haricot bean as well as selected soil properties.

1.1. Statement of the Problem

Low agricultural productivity and unbalanced agricultural output growth with population growth are prevalent in developing nations such as Ethiopia (Yimenu, 2017). The main production constraints for common beans in Ethiopia generally;-

- Production is limited by a lack of high-yielding varieties with enhanced resistance to diseases and other biotic and abiotic constraints, in addition to other production limitations (Mengel, K. and E. A. Kirkby, 2001).
- Low soil fertility and ineffective soil management have been the main issues among smallholder farmers (Mebrate *et al.*, 2022).
- Due to continuous nutrient mining, crop removal without adequate replenishment, and practices that take an uneven approach to plant nutrition, soil fertility is being lost (FAO, 2006).
- The high price of fertilizers, the minimal use of them and no use of fertilizer for common bean in smallholder farmers, lack of awareness about organic fertilizer (vermicompost) and biofertilizer (rhizobium) lead to low productivity and unfertile soil in the study area (Wulbareg agricultural office).

As a result, to increase agricultural productivity and output over the long term, new technologies must be widely embraced (Cholo *et al.*, 2023). Which means, using combined organic and inorganic fertilizers is a more cost-effective alternative that yields the best crop production when compared to using either source alone (Mwangi, 2010).

1.2. Objectives of the Study

1.2.1. General objective

- To evaluate the effect of vermicompost, rhizobia, and phosphorus on yield, yield components of common beans (*phaseolus vulgaris* L.), and on selected soil properties in Wulbareg district, Silte zone, Central Ethiopia.

1.2.2. Specific objectives

- Determining the effect of vermicompost, rhizobia, and inorganic fertilizer P on growth, yield and yield components of common bean at Wulbareg district, Central Ethiopia.
- Determine the effects of P, vermicompost application, and rhizobia inoculation on biological nitrogen fixation.
- Determine the effects of vermicompost, rhizobia and P application on selected soil properties.

2. LITERATURE REVIEW

2.1. Common Bean Production in Ethiopia

Driven primarily by agriculture, which accounts for 80–85% of employment, over 61% of total exports, and 43% of Ethiopia's GDP, agriculture is the engine of the country's economy and is essential to sustainability in food security (Degaga and Angasu, 2017). The common bean (*Phaseolus vulgaris* L.) is an annual herbaceous plant that was independently domesticated in the Andes and ancient Mesoamerica. It is currently grown all over the world for its green beans as well as its dry seeds (Broughton *et al.*, 2003).

It is a main and important legume utilized by at least 300 million people, cultivated greatly in developing countries. Its first cultivation was done about 8000 years ago in Peru and Mexico and currently it is cultivated worldwide. It is one of the most produced and consumed crops in Africa (Teh Exodus *et al.*, 2020). It is estimated that the crop meets more than 50% of the dietary protein requirements of households in sub-Saharan Africa. The yearly per capita consumption of common bean is higher among low income people who cannot pay for nutritious food stuff, such as meats and fish (Broughton *et al.*, 2003).

Ethiopia's varied agroecology makes it possible to grow a variety of crops. The country is endowed with a diverse range of plant, animal, and microbiological species due to the combination of its diverse agroecology, farming systems, socioeconomic classes, and climate zones (Atnaf *et al.*, 2015). Similarly, (Tenaw, 1990) reports that, Climate and socioeconomic factors make common beans a major pulse crop that is cultivated throughout many parts of Ethiopia.

Farmers in the southern parts of the country also use and grow it extensively for a variety of uses. Grain legumes are a valuable crop that are grown by smallholder farmers. They are the third-largest export crop, after coffee and sesame, and provide nutrition as an affordable source of protein, making up approximately 15% of total protein consumption (Getachew, 2019). Grain legumes cover nearly 13% of the nation's total cultivated land, or 1.6 million hectares (ha), and contribute 11.89% of the nation's total crop production, or 2.67 million tons (CSA, 2015). With a growth rate of 3.78 percent annually during nearly 20 years, the amount of grain legume production has increased by 71.92 percent (Kebede, 2020). Over the past 20 years, the number of farmers engaged in the production of legumes in the nation has nearly doubled, from 4.5 to 8.5 million farmers (Atnaf *et al.*, 2015; Ferede *et al.*, 2014).

Over 80 percent of Ethiopia's population which is projected to number 114 million in 2020 makes their living from agriculture, a soil based sector. The requirement to produce more per unit area is rising at an incredibly rapid rate in order to feed the nation's expanding population. A sufficient and well-balanced supply of nutrients is probably what leads to an increase in productivity in the interim. Nonetheless, decreasing soil fertility is a significant issue that has long been unresolved and affects crop productivity and food security (Elka and Laekemariam, 2020).

One of the main obstacles to crop production in arid and semiarid regions is the decline in soil fertility and organic matter contents, which is caused by high temperatures, little rainfall, and an increase in the calcareousness of these soils (Naseer *et al.*, 2019).

Shumi (2018), also reported that low soil fertility, particularly low levels of N and P, is the main factor limiting the production of common beans and accounting for up to 1.2 million tons of grain yield loss in Africa. As the demand for an increase in crop production is increasing due to the expansion of colonization on agricultural lands, farmers try to use more chemical fertilizer which declines soil biology and environmental quality. Governments all over the world are prioritizing the development of eco-friendly alternate strategies for crop production. Beneficial soil bacteria have significant impact on the growth and productivity of crop plants (Naseer *et al.*, 2019).

2.1.1. Importance of common bean (*phaseolus vulgaris* L.) in Ethiopia

In Ethiopia, the common bean is a major food crop and a substantial source of revenue; smallholder farmers cultivate the majority of the crop. Among the fastest growing legume crops, it is an essential part of most Ethiopians' daily diets and their main source of income (Van Schoonhoven and Voysest H 1991). Similarly, (Tenaw, 1990) reported that, the common bean is primarily used as a food and money source. It is also exported to generate foreign currency and is also one of the cash crops locally used by farmers. In addition to that serves as livestock feed, a means of preventing soil erosion, a source of fuel, and promoting soil fertility (Muoni *et al.*, 2019). It has also the potential to be source of plant nutrients in agricultural systems that could supplement or replace inorganic fertilizers for cereal crop production. This is because they can biologically fix nitrogen and provide an indirect source of manure based nitrogen inputs when used as animal feed (Teshome *et al.*, 2018).

2.1.2. Constraints of bean production in Ethiopia

There are several constraints and notable deficiencies that affect the productivity and production of grain legumes in Ethiopia. Despite the nation's enormous potential to produce a wide range of grain legumes and benefit from all of their various uses.

The average national yield (7.26 dt ha^{-1} and its regional productivity is 8.14 dt ha^{-1}) is low compared to the yield that is attained under research center (Gidago *et al.*, 2011). According to (Getachew, 2019) Ethiopian grain legume productivity and production seem to be severely constrained by limited or no use of chemical fertilizers, improved seeds, limited application of conventional agronomic practices, and human factors like resource access and control. In similar vein, (Tadesse and Dechassa, 2017).report that common beans are challenged by low soil fertility, poor cultural practices, lack of improved varieties, disease and pests, and environmental degradation.

Bean production faces challenges from crop mining, erosion, and low fertilizer rates that lead to nutrient depletion. Because of losses from erosion and high fixation, most soils do not always contain enough P for crop growth (Gidago *et al.*, 2011). Insecure land tenure systems in smallholder farms, limited access to input and output markets, high disease and pest incidences associated with management of legumes and cereal-dominated farming systems, and farmer unwillingness to test new legume species are some of the reasons why legume production and productivity in east Africa, including Ethiopia, are lower than expected (Muoni *et al.*, 2019).

2.2. Environmental Requirement of Common Bean

Common bean is an annual pulse crop with considerable variation in habit, vegetative characters, flower color and the size, shape and color of the pods and seeds (Onwueme and Sinha, 1991). It needs a warm, frost-free environment, although extremely hot or rainy weather can cause the plants to lose their flowers or pods. The subtropical to temperate climate that gave rise to the common bean has distinct wet and dry seasons. Beans favor regions with moderate rainfall over those with heavy or dry spells. The common bean favors sandy clay or sandy loam soils that have a moderate acidity level 5.8–6.5 pH and balanced fertility (Alhrout *et al.*, 2016).

It is well adapted to altitudes between 1200 and 2000 m above sea level (Wortmann, 1998), and areas with annual average rainfall 500-1500 mm. Temperatures of 18-24°C are ideal for growth. It is not drought resistant; ideally needs moist soil throughout the growing period. However, rainfall towards the end of growing periods is undesirable. It can be grown successfully on most soil types, from light sands to heavy clays, but friable, deep and well-drained soils are best preferred (Onwueme and Sinha, 1991).

2.3. Effect of Phosphorus on Common Bean Growth and Productivity

An important macronutrient that physically participates in multiple basic biological processes, such as photosynthesis, respiration, nucleic acid synthesis, enzyme activation/inactivation, signaling, and redox reactions is Phosphorus (P) (Zhang *et al.*, 2019). In a similar vein, (Hussain, 2017) said that it is necessary for the molecular structure of plants and aids in energy transformation and the control of a number of enzymatic processes. Additionally, most metabolic processes that take place above ground require phosphorus.

As (Havlin *et al.*, 1999) also reported the metabolism of energy transmission, signal transduction, macromolecular biosynthesis, photosynthesis, respiration chain processes, nitrogen (N) fixation, and biomass synthesis of micronutrients all benefit from phosphorus.

An essential mineral nutrient for plant growth, phosphorus is linked to early crop maturity and development, particularly for the production of sufficient grain. It is also essential for the development and growth of plants (Van Schoonhoven and Voysest, 1991). In addition to increasing crop yield, the application of chemical fertilizers containing N, P, and K improves the nutritional quality of crop yields by improving the amounts of protein, oil, starch, essential amino acids, and vitamins in pulses, oil seeds, tubers, and vegetables, respectively (Alhrout *et al.*, 2016).

Because of losses from erosion and high fixation, most soils do not always have enough P for crop growth (Brady and Weil, 2002). In the much worn acid soils that predominate in the tropical highlands, this issue is most important. In Southern Ethiopia most soils have an available P level of less than 5 mg/kg, which falls under the low P content category (Kelsa *et al.*, 1996). Phosphorus deficiency decreases plant growth and biomass production because of the significant role of P in photosynthesis, P deficiency largely affects CO₂ assimilation ability of plants (Zhang *et al.*, 2019). One of the many variables influencing the low grain production of the bean is the lack of an optimal fertilizer rate. Due to the formation of proteins containing chemicals, in which N and P are significant elements, legumes, notably common bean, have high P requirements (Getachew, 1990). The amount of P absorbed by legumes is what essentially determines how many seeds they produce. The common bean's production rises with P application, and P can also promote nodulation and nitrogen fixation (Amare, 1987).

P application is crucial to maximizing bean output because of this. Symbiotic N fixation has a high P demand because the process consumes large amounts of energy and energy generating metabolism strongly depends upon the availability of P. Root development, stalk and stem strength, flower and seed formation, crop maturity and production, crop quality, and resistance to plant diseases are the traits associated with P nutrition (Nigatu, 2017).

2.4. Rhizobium and Nitrogen Fixation

Bio-fertilizers are inputs containing microorganisms that are capable of mobilizing nutritive elements from non-usable form to usable form through biological processes, which include mainly nitrogen fixing, phosphate solubilizing and plant growth promoting microorganisms (Goel *et al.*, 1999). Chemical fertilizers are supplemented by inexpensive, renewable plant-nutrient sources called biofertilizers. One of the key elements of integrated nutrient management is the use of biofertilizer, which is a cheap and renewable source of plant nutrients that can be used to supplement chemical fertilizers in sustainable agriculture. They are also known as microbial inoculants, and they are among the greatest agricultural tools available today (Nigatu, 2017). The primary biological function of legume rhizobium symbiotic N fixation is to supply plants with fixed N. It is also essential for enhancing soil N availability. The proper Rhizobia inoculation of legumes increases nodulation efficiency, which in turn stimulates plant growth and raises grain yield (Khaitov *et al.*, 2020).

(Amha, G., and Fassil, A. 2018) claims that the legume-rhizobium symbiosis takes advantage of BNF (biological nitrogen fixation) the greatest. And a method for boosting soil fertility that shows great promise. It gives the plant roughly 65% of the biosphere's total nitrogen (Lodwig *et al.*, 2003).

Rhizobium spp. survival under BNF conditions could affect the efficiency of BNF. The effectiveness of BNF may depend on the survival of the Rhizobium spp. under different soil conditions like salinity, drought, acidity, and soil temperature (Zahran, 1999). The determining factors to assess the potency of Rhizobium spp. present in the soil are nodule presence and the rate of N₂ fixation (Amijii and Giller 1998).

Rhizobia is typically injected into legumes to stimulate plant growth, development, and yield. This method is typically used in place of the more expensive mineral nitrogen fertilizer. In leguminous plants, the rhizobia (bacteria) has the ability to infect the root, form nodules, and fix N₂ symbiotically (Asante *et al.*, 2020). Rhizobium strain inoculation boosted yield characteristics, dry matter, and bean protein content. Rhizobium inoculation greatly raised the number of seeds per pod, the number of pods per plant, the weight of 100 seeds, the yield of seeds, the weight of seeds per plant, the weight of pods per plant, the yield of protein seeds, and the amount of dry matter in the plants (Yadegari and Rahmani 2010). Rhizobium symbiosis with legumes produces 50% of 175 million tons of total biological N₂ fixation annually worldwide. 60% of all biological nitrogen fixation is attributed to the legume-rhizobia symbiosis, which produces nodules on the roots or stems of the host plant (Gedamu *et al.*, 2021).

2.5. Benefits of Vermicompost

Vermicompost is created when various microorganisms and earthworms work together to aerobically biodegrade organic materials. Vermicompost is a significant source of plant nutrients that can replace chemical fertilizers and lower crop production costs (Lazcano *et al.*, 2013).

In a similar way, vermicompost is produced by organic material being broken down by earthworms and microbes. Vermicompost has the potential to be both environmentally and economically advantageous while also maintaining the soil ecology (Eswaran and Mariselvi, 2016). Similar to this, vermicomposting is the process of turning organic waste into a secondary product called vermicompost that can be applied as a crop fertilizer by using earthworms (Blouin *et al.*, 2019).

Continued usage of chemical fertilizers results in health and environmental risks such nitrate leaching that pollutes ground and surface water (Eswaran and Mariselvi, 2016). Thus, vermicomposting presents an intriguing way to recycle the growing quantity of organic waste while also cutting back on fertilizer usage. Additionally, using composts extensively is a good way to raise the amount of organic matter in the soil, which is essential for long-term fertility (Blouin *et al.*, 2019). Vermicompost contains humic acids and sufficient nutrients for the optimum growth of plants (Ganeshnauth *et al.* 2018). According to his study, (Gopinath *et al.* 2011), there has been a notable rise in shoot length, dry weight, number of tillers per plant, number of pods per plant, and number of seeds per plant With increasing vermicompost treatment and the greatest values per pod of common bean at an 8 ton ha⁻¹ recording. Similarly, (Lim *et al.*, 2015) describe how the organic input increased growth and yield. This is accomplished by providing more readily available C, Mg, Ca, P, and K for the plant. Vermicomposts have the ability to enhance plant growth when added to the soil (Atiyeh *et al.* 2000).

Vermicompost, which is composed of digested compost and worm castings, is a great soil additive, according to Ruz-Jerez and Tillman (1992), worm castings are valued higher than Vermicompost because they contain more nutrients and microbial activity. Additionally, compared to other types of compost, the nutritional life is up to 6 times greater. (Reinecke *et al.*, 1992) stated that phosphorous is transformed into forms that are available to plants during passage through the worms' guts. As a result, any method that greatly raises the availability of phosphorus through plants and organic matter is crucial for agriculture.

In comparison with other organic fertilizers, vermicompost consists of high levels of nutrients. Studies on the effects of organic fertilizers such as vermicompost demonstrated that using this fertilizer can increase nitrogen in the soil by about 42%, phosphorus by about 29% and potassium by 57%. Due to environmental pollution, health problems and reactions caused by artificial growth enhancers, it should have used an eco-friendly fertilizer (Ceritoglu and Erman, 2020). Its contribution to better plant growth can be generally divided into four categories. Nitrogen (N), both in its organic and inorganic forms, is abundant in vermicompost and is readily absorbed by plants (Lazcano *et al.*, 2013). Vermicompost contains nitrate (NO_3^-) and ammonium (NH_4^+), both of which are plant available sources of nitrogen (N).

2.6. Effects of Combined Organic and Inorganic Fertilizer on Common Bean Productivity

Excessive use of chemical fertilizers can harm aquatic and atmospheric environments, as well as cause unfavorable changes in food. The results of numerous studies demonstrated that managing soil fertility sustainably requires more than just applying mineral fertilizers (Alhrout *et al.*, 2016).

Due to the rapid population growth and resulting increased demand for the crop, chemical fertilizers are being used extensively without regard for the quality and health of the soil, which is essential for achieving sustainable yield. In addition, there are concerns about the long-term consequences of chemical fertilizers on the environment, subsurface water, soil microbes, and crop products (Jan *et al.*, 2020).

Most people agree that one of the best ways to combat the problem of nutrient depletion and maintain food production is through the use of mineral fertilizers. Since it was discovered that both nutrients are a major issue, Ethiopia has long applied inorganic fertilizer that contains N and P in the form of urea (46N-0-0) and diammonium phosphate (DAP) (18N-46P₂O₅). This practice began about 50 years ago. Nevertheless, even though the nation's fertilizer consumption has been steadily rising, the increase in crop yield from both fertilizers is gradually decreasing over time (Elka and Laekemariam, 2020). Years of land exploitation have resulted in low soil fertility, which is a major factor in the decline in bean productivity. It gets worse because fertilizers are expensive and used sparingly in smallholder farming practices (Mwangi, 2010).

Combining organic resources with mineral fertilizer increases the effectiveness of fertilizer use (Wangechi, 2009). Continuous application of organic manures improves the soil's structure and encourages the development of microbial communities. When combined with the ability of organic manure to store moisture and release nutrients gradually, the application of inorganic fertilizers also offers a ready supply of nutrients during the early growth phases of the young crop (Cheminingwa *et al.*, 2007), thereby sustaining crop development and protecting it from unfavorable conditions.

Following repeated compost application, the soil's total and accessible P and K concentrations are each higher (Seminar proceedings - Brussels, 2001).

Nutrient management preserves soil fertility and enhances crop production's economics. It has also been demonstrated that a bean crop benefits more from a combination of organic and inorganic fertilizers than from anyone alone. Similarly (Tadesse *et al.*, 2022) report that using mineral fertilizers alone has undesirable consequences for soil microbes and the environment. The rhizobium activity and N₂ fixation are reduced when the system lacks phosphorus (P) since P serves as an energy source for the rhizobia and also stimulates early root growth and enhances the formation of lateral and fibrous root systems which are essential for nodule formation. P enhanced the efficiency of photosynthesis in plants and increased branch numbers and pods per plant thereby contributing to the yield of plants (Asante *et al.*, 2020). The combined use of rhizobial inoculants and phosphorus supplements on legumes may play a great practical role in the cropping systems of developing countries, which can increase soil fertility and plant productivity. thereby increasing the farm income of farmers. Phosphorus fertilizer application along with Rhizobium inoculants influenced nodulation and N fixation of faba bean at Wolaita Sodo (Nigatu, 2017). The author claims that tiny amounts of nitrogen from inorganic fertilizers combined with nitrogen fixed by legumes may provide a way for smallholder farmers to meet their nitrogen needs (Mwangi, 2010). Furthermore, the use of integrated nutrient management has reduced the cost of mineral fertilizer by more than half (Tadesse *et al.*, 2022). Integrated nutrient management has helped to reduce the cost of mineral fertilizer up to 50% or more (Elka and Laekemariam, 2020).

2.7. Role of Rhizobia, Vermicompost and Phosphorus on Selected Physiochemical Properties of Soil

Vermicompost has significant effects on the soil's physical properties. According to (Ferrerias, *et al.* 2006) the addition of 20 t ha⁻¹ vermicompost to an agricultural soil in two consecutive years significantly improved soil porosity and aggregate stability and the number of large elongated soil macro pores increased significantly after a single application of a dose of vermicompost equivalent to 200 kg·ha⁻¹ of nitrogen to a field. (Gopinath, *et al.* 2008) a significant decrease in soil bulk density and a significant increase in soil pH and total organic carbon after the application of vermicompost will be observed. Vermicompost not only adds microbial organisms and nutrients that have long-lasting residual effects, it also modulates the structure of the existing soil, and increases water retention capacity (Al-Chammaa *et al.*, 2014). vermicompost increases the soil content in organic matter, which in turn decreases the soil bulk density and increases the availability of water and mineral nutrients, it has hormone like effects, and it lowers the impacts of pests and pathogens (Blouin *et al.*, 2019).

P also has a great role in the physicochemical properties of soil. There is a significant change in the approximate maximum water-holding capacity of soil when phosphorus is applied (Lutz J F *et al.*, 1966). A balanced application of fertilizers (N, P, and K) and manures can increase soil organic carbon levels in agricultural soils. P fertilization enhances C and N concentrations in soil aggregates, increases aggregation and improves soil structure; improves bulk density and tilth (Ibrahim and Rattan 2012).

Rhizobia plays a significant role as reported by Sylvie and Patrick (2010), macronutrient Ca and Na and micronutrient Cu, Zn, Fe and Mn significantly increased by Rhizobium inoculation. And also increase pH value. A lack of suitable rhizobial strains causes poor nodulation, flower drop and pod shedding (Rafique *et al.*, 2021).

2.8. Biological Nitrogen Fixation

Biological nitrogen fixation (BNF) is a physiological process that facilitates agricultural crop production by adequate N supply (Rafique *et al.*, 2021). It is the process in which nitrogen gas (N_2) from the atmosphere is incorporated into the tissue of legume plants, with the help of soil microorganisms. It is the symbiotic relationship that results in the formation of a specialized structure called nodules. The bacterial micro symbiotic fixes nitrogen for the macro symbiotic which is the legume plant in return for reduced carbon (C) from the plant host to the micro symbiotic which is the rhizobia bacterium (Gyaneshwar *et al.*, 2002).

Biological nitrogen fixation, which is the conversion of atmospheric nitrogen to ammonia by microorganisms in root nodules of legume plants, plays a significant role in the global nitrogen cycle and in world agriculture (Gedamu *et al.*, 2021). Atmospheric nitrogen (N) is fixed by forming a symbiotic relationship with specific soil bacteria, which can then be converted into a usable form for growth and development (Shanka *et al.*, 2018).

Furthermore, seeds and root molecules mainly flavonoids are secreted by legume plants which can be sensed by some specific species of rhizobia (Makoi and Ndakidemi, 2013). The nodule then appears on the roots and facilitates the nitrogen-fixing bacteria (Santos *et al.*, 2013). Plants absorb most of the nitrogen in the ammonium (NH_4^+) and nitrate (NO_3^-) forms.

Only a limited number of prokaryotes are able to convert the N_2 molecule into a usable form of N through a process known as biological nitrogen fixation (BNF) (Allito *et al.*, 2015). leguminous plants are associated with an array of bacteria having the ability to reduce atmospheric (inert N_2) into a form available for plants through BNF (Rafique *et al.*, 2021).

BNF is done by both free-living organisms (e.g. Azotobacter, Beijerinckia, Clostridium, Bacillus, Klebsiella, Chromatium and Rhodospirillum) and those that form symbiotic associations with other organisms (e.g. Rhizobium). In agricultural settings, perhaps 80% of this biologically fixed N comes from symbiosis involving leguminous plants (Nigatu, 2017).

Only rhizobia that are specifically compatible with a particular species of legume can stimulate the formation of root nodules, a process called nodulation. The importance of BNF through N fixing soil organisms goes back more than 100 years (Eaglesham, 1989). Next to photosynthesis, N fixation is the second most important process in crop production. Photosynthesis captures sunlight and produces energy, and N fixation uses nitrogen gas (N_2) to form ammonium (NH_4^+). BNF is an efficient source of N and it can provide for free up to 300-400 kg N_2 ha⁻¹ year⁻¹ (Peoples *et al.*, 1995).

2.8.1. Methods to quantify biologically fixed nitrogen

Many techniques have been developed to measure the BNF, or the percentage of nitrogen that is derived from air (%Ndfa) (Yu *et al.*, 2010). The acetylene reduction assay (ARA), xylem-solute (or ureide production) method, the use of ¹⁵N labelled compounds (¹⁵N natural abundance, A-value method (AV), use of ¹⁵N enriched fertilizers, use of ¹⁵N₂ gas) and the total nitrogen difference (TND) method are the four commonly used methods for measuring biological nitrogen fixation (BNF) in plants (Danso, 1995).

In the acetylene reduction assay method, nodulated roots are incubated in acetylene and ethylene produced after a specific time as measured by gas chromatograph. It provides only point measurements of nitrogenase activity as measured by gas chromatograph (Hardarson and Danso, 1993). Instead of reducing N_2 to NH_3 , it depends on nitrogenase's preferential reduction of acetylene (C_2H_2) to ethylene (C_2H_4). In this method, N_2 fixing bacteria were cultivated in a particular medium under the necessary conditions. The number of bacteria increased and was counted after the necessary amount of time (Das and De, 2018). The acetylene reduction assay has shown to be a valuable method for choosing species or cultivars to utilize as non- N_2 -fixing reference plants, as well as a sensitive diagnostic tool for detecting nitrogenase activity (Peoples *et al.*, 2002).

N-containing compounds, which are carried by the xylem sap from the roots to the shoots, are measured and compared in the xylem-solute technique. Either mineral N absorbed from soil or assimilation products of N_2 fixing nodules are these compounds (Hardarson and Danso, 1993). In many tropical and sub-tropical legumes, the main product of N_2 fixation exported from the nodules is in the form of allantoin and allantoic acid (ureides). Solutes originating from the soil mineral N are carried by these same species' xylem either as nitrate or as the organic byproducts of nitrate reduction (amino acids) (Peoples *et al.*, 2002).

Isotope-based techniques are popular in quantifying N_2 -fixation and the Use of ^{15}N enriched fertilizers (^{15}N isotope dilution) technique is used widely for measuring time integrated biological nitrogen fixation in field settings (Hossain *et al.*, 2016). It involves the growth of N_2 -fixing and non- N_2 -fixing reference plants in soil fertilized with ^{15}N -enriched inorganic or organic fertilizer (Hardarson and Hera, 1998).

The natural abundance method utilizes the difference in ^{15}N natural abundance between N_2 -fixing and non-fixing plants to estimate the contribution of atmospheric N_2 for N acquisition (Houngnandan *et al.*, 2008). (Raji *et al.*, 2019) also used ^{15}N natural abundance method to estimate biologically fixed nitrogen.

In the A-value method it is necessary to apply different doses of N to fixing and non-fixing plants. it is practical to give a reasonable dose of N-labelled fertilizer (40-80 kg N/ha) to the reference crop, while the fixing crop receives a low quantity (10-20 kg N/ha) (Danso, 1995). use of $^{15}\text{N}_2$ method uses ^{15}N enriched gas in which nitrogen-fixing systems are incubated (Hardarson and Danso, 1993).

One of the earliest and most straightforward methods is the total nitrogen difference (TND) method, which has produced numerous useful estimates of biologically fixed N_2 and served as the foundation for numerous management strategies (Danso, 1995). The N-difference process aims to divide plant nitrogen into fractions that come from either atmospheric or soil nitrogen. This is accomplished by contrasting the quantity of N that the N_2 -fixing plant under study accumulated with that of a non- N_2 -fixing plant. It is assumed that the amount of N in the non- N_2 -fixing plant represents the amount of mineral N in the soil that is available to plants for growth during the growing season (Peoples *et al.*, 2002). It has been widely used and is based on the assumption that the amount of soil mineral N (N_{min}) available to the N_2 -fixing and the non- N_2 -fixing plants is the same at the same time (Yu *et al.*, 2010). Similarly, (H. Yakubu *et al.*, 2010) used N difference method to estimate biological nitrogen fixation. Examples of reference plants include weeds, or non- N_2 -fixing mono- or dicotyledonous crops (Balboa and Ciampitti, 2020). There are numerous comparative advantages to the TND method.

Simplicity, speed, affordability, and ease of implementation for those without a lot of experience (Bado *et al.*, 2018). It is known to have comparable results with ^{15}N Isotope dilution method, is a cheap and simple way to quantify N_2 fixation (Joy and Flora, 2013).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study area Bilawanja is located in the Central Ethiopia region, Silte zone, Wulbareg District (figure 1). It is 188 km far from the Southwest of Addis Ababa. The geographical location of the area is 7°45' 62" latitude, 38° 10' 58" longitude, with an altitude of 1936 m.a.s.l. The duration of the main rainy season is from July to October. The average maximum and minimum temperature were adequate for common bean production. The main crops cultivated in the area include maize, wheat, teff, common bean, chick bean, finger millet and cabbage.

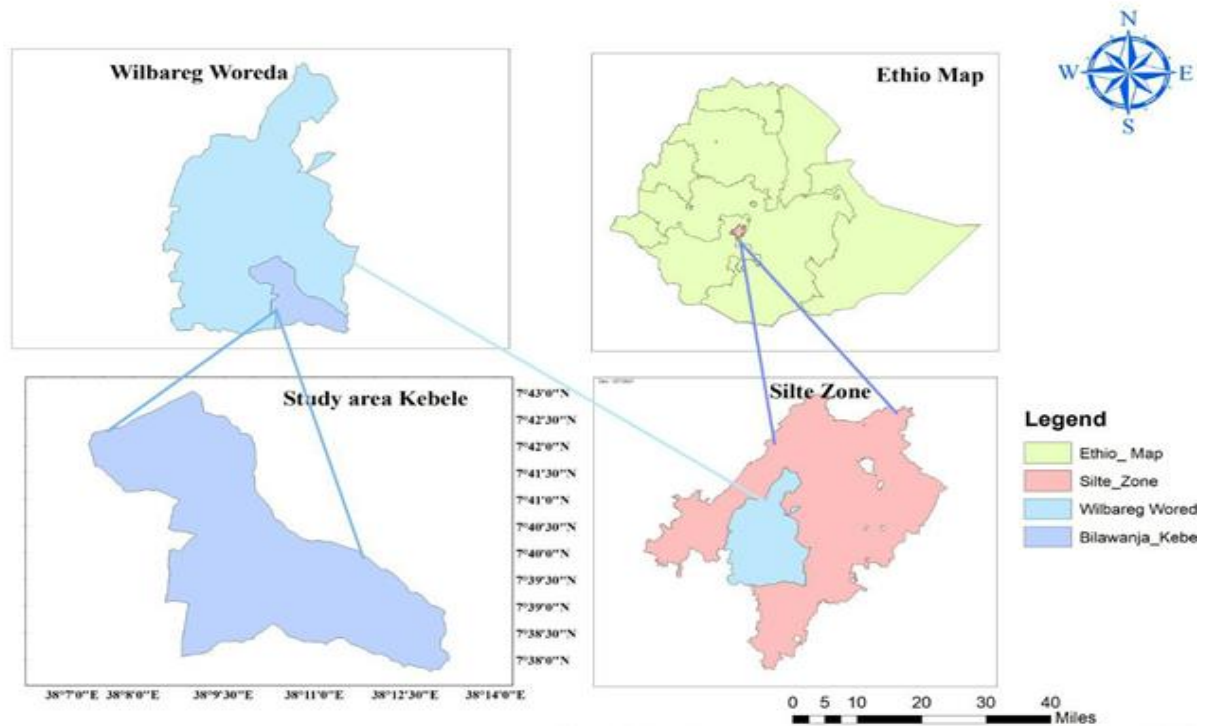


Figure 1: Administrative map of SNNPR where Silte Zone, Wulbareg District, and experimental sites (bilawanja kebele) are located.

The study district has bimodal rain-fall pattern (Belg and Meher seasons). The experimental site had a total amount of rainfall 541.3 mm and a mean minimum temperature of 13.53°C and mean maximum -temperature of 24.05 °C from July up to October during the growing season 2022 (Figure 2). Thus, an adequate amount of rain falls and an ideal temperature is maintained for common bean production. It requires 300–400 mm of water during its growth period and should be maintained above 50% during flowering and seed filling phases. It grows optimally at temperatures of 18–24 °C.

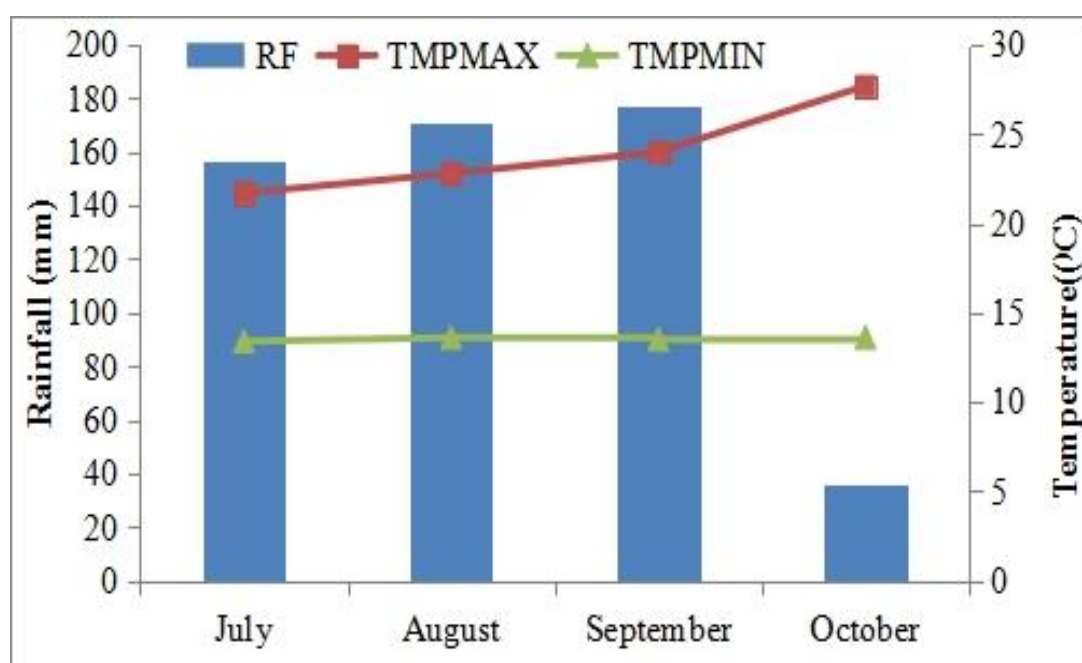


Figure 2: Monthly total rainfall (mm) means the minimum and maximum temperature of the experimental district during the production season in 2022.

Source: (EMI, 2022).

3.2. Sources of Planting Materials

P fertilizer used for the experiment was obtained from Hawassa University College of agriculture soil laboratory. Rhizobium strain was bought from Addis Ababa Menagesha Biofertilizer Industry and vermicompost used for the experiment was bought from Wondogenet Woreda Lemlem Vermicompost Interprise. Common bean (Hawassa dume cultivar) was obtained from Hawassa Agricultural Research Center.

3.3. Treatments and Experimental Design

Treatments consist of three levels of P (0, 20, and 40 kg ha⁻¹), three levels of vermicompost (0, 4, and 8 ton ha⁻¹) and two levels of rhizobium (with and without rhizobium inoculation) arranged in factorial combination using randomized complete block design (RCBD) with three replications. There were eighteen treatment combinations including the control.

Table 1: Treatment combination used in the experiment.

Treatments No	Treatment combination	Phosphorus kg/ha-1	Vermicompost ton ha-1	Rhizobium
1	Control	0	0	Non-inoculated
2	HB+I	0	0	Inoculated
3	4Vc-I	0	4	Non-inoculated
4	8Vc-I	0	8	Non-inoculated
5	4Vc+I	0	4	Inoculated
6	8Vc+I	0	8	Inoculated
7	20P-I	20	0	Non-inoculated
8	40P-I	40	0	Non-inoculated
9	20P+I	20	0	Inoculated
10	40P+I	40	0	Inoculated
11	20P+4Vc-I	20	4	Non-inoculated
12	20P+4Vc+I	20	4	Inoculated
13	20P+8Vc-I	20	8	Non-inoculated
14	20P+8Vc+I	20	8	Inoculated
15	40P+4Vc-I	40	4	Non-inoculated
16	40P+4Vc+I	40	4	Inoculated
17	40P+8Vc-I	40	8	Non-inoculated
18	40P+8Vc+I	40	8	Inoculated

3.4. Experimental Procedures and Management

The field was ploughed to get a fine seedbed using an oxen plow and the plots was leveled manually. Plot area was 9.6 m² with a distance of 0.5 m and 1 m between plots and blocks, respectively. A spacing of 40 cm and 10 cm between rows and plants respectively was used during planting.

Triple super phosphate (TSP) was used as a source of P and applied at sowing time. For rhizobium inoculum, 20 g of sugar was mixed with 200 ml of water for one pack of (125g inoculum) rhizobia. The thick slurry of the inoculant was gently mixed with dry seed manually and then all seeds received a thin coating of the inoculant. Inoculation done just before planting under shade to maintain the viability of rhizobial cells. Haricot bean (variety Hawassa dume) was sown using two seeds per hill at the beginning of the rainy season. After emergence, the seedlings were thinned to one seedling per hill removing diseased and weak plants. A local variety of wheat was sown by adding one plot on each block as a reference crop for estimating biological nitrogen fixation. All other crop management and protection practices were applied uniformly to all plots.

3.5. Data Collection

3.5.1 Soil sampling and preparation

Soil samples were collected from 0–20 cm depth randomly from different spots in the experimental field before planting by using a soil auger and composited, with 10 subsamples per composite.

Then, the collected samples were air-dried at room temperature and ground to pass through a 2 mm sieve for laboratory analysis of soil texture, organic carbon (OC), cation exchange capacity (CEC), soil pH and available phosphorus using the standard soil laboratory procedures. The sieved soil material was allowed to pass through 0.2 mm sieve for soil organic carbon and total nitrogen determination. Soil bulk density and soil moisture content were determined by collecting undisturbed soil samples from the experimental field by using a core sampler.

3.5.2. Phenological and growth parameters

Days to 50% flowering: This refers to the actual number of days required by the plants from emergence to a stage when 50% of the plants in the plot produced flowers. This was determined by counting.

90% physiological maturity: This was recorded as the number of days from emergence to the time when about 90% of the plants in a plot had mature pods in their upper parts with pods in the lower parts of the plants turning yellow.

Plant height (cm): Plant height was measured at physiological maturity from the soil surface to the apex of each plant on ten randomly selected plants from the central unit area.

Number of primary branches per plant (number): This was determined by counting primary branches on the main stem from randomly taken five plants from each net plot at physiological maturity.

3.5.3. Nodulation parameters

Total Number of nodules (number): Five bean plants were randomly taken from each plot to count nodules at mid-flowering (50% flowering) stage. The soil around the roots was dug to loosen and the plants were uprooted carefully. The muddy roots were washed in a bucket where the nodules easily be seen and counted.

Effective number of nodules (number): Roots were carefully washed under gently flowing tap water on a screen and nodules were separated and counted. The effectiveness of the nodules was checked by cutting the nodule for color judgment as a percentage of the pink being effective and the cream (white) ineffective.

3.5.4. Yield components and yield

Crop stand count (number): The plants from the net plot area were counted at the establishment and crop harvesting period and the plant population per hectare was obtained.

Number of pods per plant (number): five plants were randomly taken from central rows and pods were counted and a mean number of pods per plant was determined at physiological maturity.

Number of seeds per pod (number): Seeds in each pod were counted from ten randomly taken plants per plot and the average number of seeds per pod was determined.

Grain yield (kg ha^{-1}): Grain yield was measured from the harvested central unit areas (6.72 m^2). Grains cleaned following harvesting and threshing, weighed using balance, and adjusted to 10% moisture content using the formula.

Adjusted grain weight (g) = Recorded grain weight x (10/M)

Where:- M is the measured moisture content in the grain.

1000 seed weight: a thousand seeds were counted from the harvested bulk of each plot and their weight was recorded and adjusted at 10% moisture content.

Aboveground dry biomass yield (kg ha^{-1}): was measured from the net plot area (6.72 m^2) including leaves, stems and seeds which was harvested at physiological maturity just before cob removal and weighed after three days of sun drying. Aboveground standing dry mass of live or dead matter from sample plants is expressed as a mass per unit area. The harvested plants dried to constant weight at 60°C and weighed using a balance to determine the above-ground biomass yield per net plot area .

AGB=Dry sample weight/ Sampling area = g/m^2

Harvest Index (%): Was calculated as the ratio of grain yield of harvestable row to total aboveground dry biomass yield multiplied by 100.

3.5.5. Post-harvest soil sampling and laboratory analysis

Composite soil samples were collected from each plot after harvest from 0-20cm depth by auger and the effects of phosphorus, vermicompost and rhizobium application on selected soil properties including bulk density, soil moisture content, OC, TN, available P, CEC and soil pH were determined.

Soil sampling for determination of the effect on soil moisture content was carried out 4 times. One sample before planting and 3 times at a monthly interval (30^{th} days, 60^{th} days and 90^{th} days) during the growing season for each plot and fresh weight was recorded in the field.

Samples were oven dried at 105°C for over night and weight was recorded. The moisture content in (%) by weight was calculated by the following formula (Garza-Reyes, 2012).

$$\text{Percent moisture (wt \%)} = \frac{\text{weight of fresh soil} - \text{oven dried soil}}{\text{oven dried soil}} \times 100$$

Sample for determination of bulk density was taken three sample per plot from each plot by core sampler. The weight of the sample was taken in the field and oven dried at 105°C in the laboratory. The determination method of bulk density is called core method (Blake and Hartge, 1986). It was calculated by:

$$\text{BD} = \frac{\text{dry weight of the soil (g)}}{\text{volume of core sampler (m}^3\text{)}}$$

The pH and Electrical Conductivity (EC) were measured from soil suspension of 1 : 2.5 (weight/volume) soil-to-water ratio using a digital pH meter. Organic carbon was analyzed by using –the (Walkley and Black 1934) method. Soil organic matter was calculated from organic carbon using the formula: OM = 1.724 x %OC. Available phosphorus analyzed by the Olsen method(Olsen *et al.*, 1954). Cation Exchange Capacity (CEC) was determined after extracting the soil samples using ammonium acetate (1 N NH₄OAc) at pH 7.0 (Chapman 1965). The soil texture analysis was carried out using the hydrometer method (Bouyocous, 1962). Total nitrogen was determined using the modified Kjeldahl method as described by (Bremner, 1996).

3.5.6. Estimation of biological nitrogen fixation (BNF)

At maturity, aboveground plant biomass was sampled from a 1.5 m² area in each plot, oven-dried at 70 °C for 48 hours.

Wheat (Ogolcho variety) was planted on three plot at the end of each block of common bean. The plot area was 4.8 m² which was (1.5m x 3.2m) and spacing between rows was 20 cm. Seeds of N-fixing and non fixing crops were threshed and weighed, and straw yield was recorded using a sensitive balance. The samples were milled using a grinder and prepared for laboratory analysis. Shoot N contents of haricot bean and non-N₂-fixing crop (wheat) were determined using Kjeldhal digestion method (Bremner, 1996). The Kjeldahl procedure is based on the principle that by treating plant material with concentrated sulfuric acid it is oxidized and nitrogen in the plant material is converted into ammonium sulfate during the oxidation. The ammonia liberated in the distillation process with NaOH is trapped by the acid. The ammonia is adsorbed in the form of NH₄⁺ ion in boric acid and back-titrated with standard H₂SO₄ (Sahlemedhin and Taye 2000). As described by (Hossain *et al.*, 2016) Nitrogen accumulation in seed and straw was calculated as the product of biomass and N concentration of the plant parts.

The quantity of N fixed by a legume was calculated by the traditional N difference method (Yu *et al.*, 2010) by using wheat grown in the experimental plots as a non-fixing reference crop to determine the effects of rhizobia inoculation, phosphorus and vermicompost application on the estimate of biologically fixed nitrogen (BNF). The N-difference method is uncomplicated, quick and easy to practice and attempts to separate plant N into fractions originating from soil N or atmospheric N₂. This was done by comparing the amount of N accumulated by the N₂-fixing plant (common bean) under investigation with a neighboring non-N₂-fixing crop. The N present in the wheat was taken to denote a measure of the amount of soil mineral N available for plant growth during the growing season.

It is assumed that the N₂-fixing species takes up the same amount of soil N as non-fixing crop (Peoples *et al.*, 1989). There are numerous comparative advantages of the TND method such as simplicity, speed, affordability, and ease of implementation for those without a lot of experience. The amount of total nitrogen, N₂ fixed and %Ndfa was calculated by the following formula:

$$\text{Total N in plants} = \frac{\text{Dry matter weight} \times \%N \text{ in plants}}{100}$$

$$N_{2 \text{ fixed}} = N_{\text{fixer}} - N_{\text{reference}}$$

Where, N₂ fixed indicates nitrogen fixed (kg N ha⁻¹), N_{fixer} indicates haricot bean Nitrogen, N_{reference} indicates the reference crop which is wheat.

$$\%N_{\text{dfa}} = \frac{N_{\text{fixer}} - N_{\text{ref}}}{N_{\text{fixer}}} \times 100$$

Where, N_{dfa} indicates nitrogen fixed from the atmosphere (kg N ha⁻¹), N_{fixer} indicates haricot bean Nitrogen, N_{ref} indicates the reference crop which is wheat.

3.6. Data Analysis

Data collected were subjected to analysis of variance (ANOVA) appropriate to the factorial experiment in RCBD according to the General Linear Model (GLM) procedure of SAS version 9.4 (SAS Institute, 2014) and interpretations were made following the procedure described by (Gomez and Gomez 1984). When the effects of the treatments were found significant from the ANOVA test, the means were compared using the least significance difference (LSD) test at 5% level of significance.

3.7. Selected Soil Physicochemical Properties of the Experimental Soil and Vermicompost

3.7.1. Selected soil physicochemical properties of the experimental site

The laboratory results indicated that the soil textural class of the experimental site was loam, with relative proportions of clay, silt and sand. The bulk density of soil before planting was 1.31 g cm^{-3} . pH value of the soil of the experimental site was 5.38. The ECe value of the experimental site was 0.86 ds/m. The total nitrogen and organic carbon content of the soil before applying fertilizers were 0.08 and 0.97%, respectively. The level of phosphorus for the experimental soil before the application of the treatments was 6.03 mg kg^{-1} . The result showed that the cation exchange capacity of the experimental soil was $40 \text{ cmol (+) kg}^{-1}$.

Table 2: Selected soil physicochemical properties of the experimental site.

Parameters	Value	Rating for soil	Reference
Silt (%)	36		
Sand (%)	45		
Clay (%)	19		
Textural class	Loam		
Bulk density (gcm^{-3})	1.6	Moderate	(Hazelton and Murphy, 2019),
Moisture content (%)	26.37		
pH	5.38	Strongly acidic	(Hazelton and Murphy, 2019),
ECe ds/m	0.86	Non-saline	(Hazelton and Murphy, 2019),
Total nitrogen (%)	0.08	Low	(Hazelton and Murphy, 2019)
Organic carbon (%)	0.97	Low	(Hazelton and Murphy, 2019)
Organic matter (%)	1.67	Low	(Hazelton and Murphy, 2019)
Available P (mg/kg)	6.03	Low	(Hazelton and Murphy, 2019),
CEC (cmol (+) kg^{-1})	40	Very high	(Hazelton and Murphy, 2019),

3.7.2. Selected physico-chemical properties of vermicompost

Vermicompost which is prepared from coffee husks, animal manure, fruit and vegetables scraps samples were analyzed for the physicochemical properties of VC including VC moisture, pH, available phosphorus, total nitrogen, CEC (cation exchange capacity), exchangeable calcium, magnesium, sodium, and potassium. (Table 3). The analysis result revealed that the pH 8.14 which is moderately alkaline and EC of vermicompost was 2.91 dS m⁻¹ slightly saline (Hazelton and Murphy, 2019). Total nitrogen and organic carbon in the vermicompost were found to be 0.93% and 12.5%, respectively. The available phosphorus in the vermicompost was found to be 642.8 mg/kg. The C:N ratio of about 13.41 which is medium. the medium carbon to nitrogen ratio in the vermicompost indicates that the compost is well decomposed and N can be released to soil for plant use (Hazelton and Murphy, 2019).

Table 3: Physico-chemical properties of vermicompost.

Parameters	Value
Moisture content (%)	39.2
pH	8.14
ECe ds/m	2.91
Total nitrogen (%)	0.93
Organic carbon (%)	12.45
Available P (mg/kg)	642.8
C:N	13.41
Ca(cmol (+) kg-1)	28.92
Mg(cmol (+) kg-1)	12.36
Na (cmol (+) kg-1)	1.78
K (cmol (+) kg-1)	25.65
CEC (cmol (+) kg-1)	57.18

4. RESULTS AND DISCUSSION

4.1. Effect of Phosphorus, Vermicompost and Rhizobia Inoculation on Selected Soil Physico-Chemical Properties After Harvest

4.1.1. Bulk density

Sole application of vermicompost ($p < 0.001$) and two factor interaction of vermicompost x phosphorus ($p < 0.01$) significantly influence the bulk density of the soil. While the sole application of rhizobia and phosphorus was not significant. Additionally, the rest two factor interaction and three factor interaction were not significant. The application of phosphorus combined with vermicompost significantly decreases the bulk density of soil. The minimum (1.1 g cm^{-3}) bulk density resulted from the interaction effect of phosphorus 40 kg P ha^{-1} with 8 t ha^{-1} vermicompost while the highest (1.39 g cm^{-3}) was from phosphorus 0 kg P ha^{-1} with 0 t ha^{-1} vermicompost (Table 4).

The reason behind this result might be earthworms found in vermicompost. Earth worms decreased the bulk density of soil. This result was supported by Rajalekshmi K (1996), bulk density of worm cast soil was significantly lower than that of uncast soil. The addition of phosphorus and vermicompost decreased the bulk density of soil. Because vermicompost contains quite level of organic matter and chemical characteristics. Organic matter regulates soil aggregation and increases soil porosity (Aktas and Yuksel, 2020). Also corroborated with the result reported by Kaur *et al.*, (2023), the maximum bulk density (1.37 g/cm^3) was recorded in the treatment control while the was the lowest (1.26 g/cm^3) in treatment with 3 t/ha Vermicompost + Rhizobium + PSB (phosphorus solubilizing bacteria).

The interaction effects of N P K, Rhizobium and Vermicompost significantly had influence on bulk density (Mg m^{-3}) of soil. The maximum bulk density of soil after crop harvest was recorded as 1.39 Mg m^{-3} in T_0 (control) (Singh *et al.*, 2017). Similarly, Increasing VC doses reduced the soil bulk density. Mean bulk density values decreased from 1.28 g cm^{-3} to 1.20 g cm^{-3} with the VC treatments (Demir, 2019). The lowest value of bulk density (0.91 g cm^{-3}) was observed from plots treated by 15 t ha^{-1} VC + 100 kg ha^{-1} NPS fertilizer (Emamu and Wakgari 2021).

Table 4: Interaction effect of phosphorus x vermicompost on bulk density of soil.

Phosphorus (kg/ha)	Vermicompost (ton/ha)		
	0	4	8
0	1.39 ^a	1.13 ^{bcd}	1.11 ^{cd}
20	1.18 ^{bcd}	1.23 ^b	1.13 ^{bcd}
40	1.22 ^{bc}	1.15 ^{bcd}	1.10 ^d
LSD	0.1106		
CV (%)	5.37		

Where:- LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation; Means in columns followed by the same letters are not significantly different at 5% level of significance.

4.1.2. Soil Moisture Content

The moisture content of the soil after 30, 60 and 90 days had significantly affected by the sole application of vermicompost. Similarly, two-factor interaction of (phosphorus x vermicompost) and (rhizobia x vermicompost) significantly influence moisture content of the soil after 30, 60 and 90 days. While main effect of phosphorus and rhizobia did not influences the moisture content of the soil. On the other hand three-way interaction of (phosphorus x vermicompost x rhizobia) significantly ($p < 0.01$) affects the moisture content of soil after 30, 60 and 90 days.

The highest moisture content after 30 days (30.16%), 60 days (21.42%) and 90 days (15.48%) were obtained from the application of 4 t ha⁻¹, 4 t ha⁻¹ and 8 t ha⁻¹ vermicompost respectively. while the lowest moisture content after 30 days (26.79%), 60 days (18.87%) and 90 days (13.06%) was from the control plot (figure 3).

This result was inline with the result of Manivannan *et al.*, (2009), the application of 5 ton ha⁻¹ vermicompost significantly increased the water-holding capacity of the soil. Demir (2019), also got significant increase in water-holding capacity of soils with 5% VC treatment. An application of organic manures significantly increased the water-holding capacity of soil (Rai *et al.*, 2014). Shimelis and senait (2023), also pointed out the highest result of 5t ha⁻¹ vermicompost on soil moisture content after 30, 60 and 90 days of soil moisture sampling. All the treatments applied combination of VC with P and rhizobia were improved soil moisture content over control and P and rhizobia alone. This might be due to enrichment of soil with vermicompost which have high water retaining capacity, higher porosity, better aggregation and low bulk density.

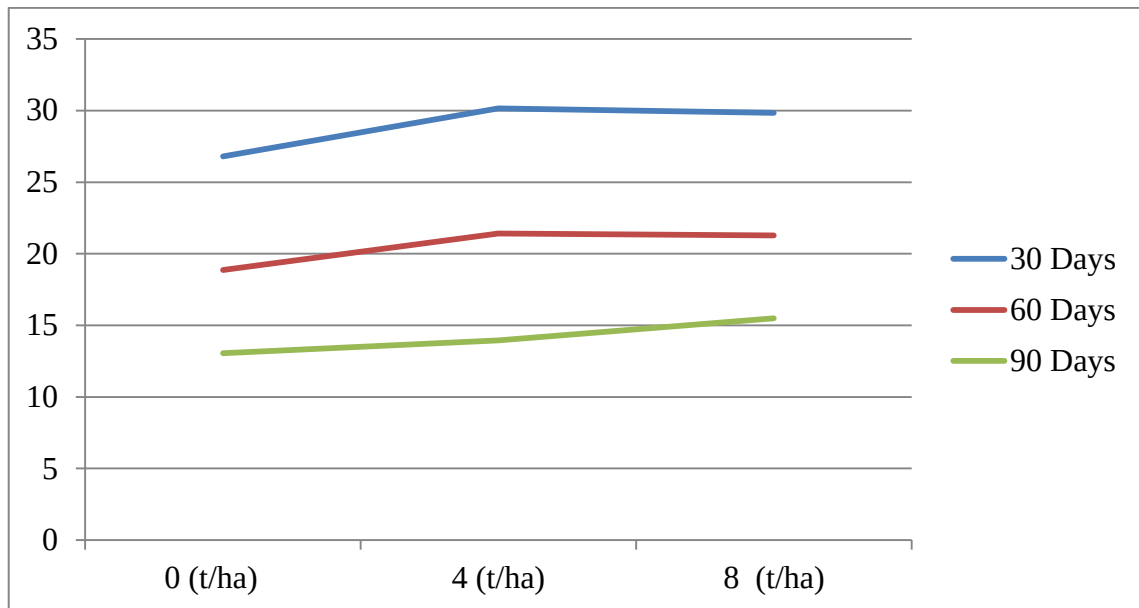


Figure 3: Effect of vermicompost on moisture content of soil (%).

4.1.3. Soil reaction (pH) and electrical conductivity

The analysis of variance showed that there was significant ($P < 0.01$) effects in soil pH values by the main effect of vermicompost. While the main effect of phosphorus and rhizobia were not significant. Similarly, all two-factor interactions had no significant effect on soil pH. Moreover, three-factor interactions were not significant. The main effect of vermicompost application significantly ($p < 0.01$) influenced the soil pH value of the experimental site. The highest soil pH value (5.61) was recorded from the treatments that received 8 tons of vermicompost ha^{-1} while the lowest soil pH value (5.45) was recorded from the treatments that received 0 ton of vermicompost ha^{-1} (Table 5). Similarly, Abate (2023), reported that the effect of vermicompost as, soil pH was highly significantly affected by the main effect of vermicompost rate. Kaur *et al.*, (2023), also agree with this study result. High pH (7.92) was observed with the treatment 5 t/ha Vermicompost. Devi *et al* (2013), confirm as, the soil pH was largely maintained in manure-treated plots.

Maximum increased in soil pH (5.60) was recorded from the integration of inorganic fertilizers with organic manures and Vermicompost at the rate of 1 t ha⁻¹. The increment in pH as rate of vermicompost increase might be the high pH value of the vermicompost (Emamu and Wakgari, 2021).

The electrical conductivity (ECe) measurement identifies soils, which are potentially saline (Okalebo *et al.*, 2002). The analysis of variance illustrated that the main effect of phosphorus, Rhizobium and vermicompost did not have a significant influence on electrical conductivity (ECe). In the same way the two-factor interaction of phosphorus x Rhizobium, phosphorus x vermicompost and Rhizobium x vermicompost did not affect this parameter.

Moreover, the three-factor interaction of phosphorus x vermicompost x Rhizobium did not have a significant influence on electrical conductivity (ECe) of soil.

4.1.4. Cations exchange capacity (CEC)

The analysis of variance showed that only the main effects of vermicompost ($P < 0.01$) highly significantly influence CEC of the soil. While the main effects of phosphorus and rhizobia, two factor interaction of phosphorus x rhizobia, phosphorus x vermicompost and rhizobia x vermicompost was not significant. Moreover the three-factor interaction of phosphorus x rhizobia x vermicompost did not influence significantly. Accordingly, the highest CEC of 44.5 cmol⁺ kg⁻¹ was obtained from the application of 8 t ha⁻¹ vermicompost while the lowest 42.77 cmol⁺ kg⁻¹ CEC value was recorded for soil from the control plots (Table 5).

The result was inline with Abate (2023), the highest CEC (26.61 meq/100) and the lowest CEC (24.38 meq/100) was recorded from the pot that received 15 ton/ha vermicompost and pot treated with lower vermicompost rate respectively.

Alkobaisy (2020), mentioned that the addition of vermicompost to the soil could reach the exchange capacity of 200cmol kg^{-1} and increase the activity of microorganisms that decompose organic matter worked to increase soil. Similarly, Nada *et al* (2011), reported that vermicompost has high Cation exchange capacity. Thus, the application of vermicompost have helped to an increase the cation exchange capacity of the soil and thereby to retain more of the cations in harvested sites.

Table 5: main effect of vermicompost to pH and CEC (cmol kg^{-1}) of soil.

VC(t/ha)	pH	CEC
0	5.45 ^b	42.77 ^b
4	5.58 ^a	43.16 ^b
8	5.61 ^a	44.5 ^a
LSD _{0.05}	0.1103	1.122
CV (%)	2.93	3.8

Where:-LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation; Means in columns followed by the same letters are not significantly different at 5% level of significance. VC= vermicompost.

4.1.5. Organic carbon

The analysis of variance showed that the main effects of phosphorus, Rhizobium and vermicompost were significantly ($P < 0.01$) influenced organic carbon content of the soil. Similarly two factor interaction of phosphorus x Rhizobium significantly ($P > 0.05$) affected the organic carbon. But two-factor interaction of phosphorus x vermicompost, Rhizobium x vermicompost and three factor interaction of phosphorus x Rhizobium x vermicompost were not significant.

The highest soil organic carbon value (2.91%) was recorded from the treatments that received 40 kg P ha⁻¹ with rhizobia inoculation while the lowest soil organic carbon value (2.02%) was recorded from the treatments that received 0 kg P ha⁻¹ with out rhizobia inoculation (Table 6).

The findings of a similar study indicated that the interaction effect of rhizobia and phosphorous fertilizer significantly affect soil organic C. The highest soil organic C was obtained from P fertilizer (92 kg ha⁻¹) along with rhizobium strain. Organic carbon significantly increased in the rhizosphere soil of rhizobium inoculated (Chimdi *et al.*, 2022). In similar vein, the application of Rhizobium inoculation combined to phosphorus and nitrogen fertilizer recorded the highest soil C while the control recorded the lowest (Hasan, 2018). This significant increment in organic carbon might be due to an increase in the soil organic carbon content with the addition of the good rhizobium types. The increase in organic C might be attributed to better root growth and deposition of organic materials in the first cropping season (Chimdi *et al.*, 2022).

4.1.6. Total nitrogen content

The analysis of variance showed that the main effects of phosphorus, Rhizobium and vermicompost were significantly ($P < 0.01$) influenced total nitrogen content of the soil. Similarly two factor interaction of phosphorus x Rhizobium significantly ($P > 0.05$) affect the total nitrogen content of the soil. But two factor interaction of phosphorus x vermicompost, Rhizobium x vermicompost and three factor interaction of phosphorus x Rhizobium x vermicompost were not significant.

The highest soil total nitrogen value (0.25%) was recorded from the treatments that received phosphorus 40 kg P ha⁻¹ with rhizobia inoculation while the lowest soil organic carbon value (0.17%) was recorded from the treatments that received 0 kg P ha⁻¹ with out rhizobia inoculation (Table 6).

This significant increment in total N might be by the rapid action of rhizobium inoculation in improving soil nitrogen concentration. According to Hasan (2018), report, the application of treatments significantly increased soil total N values in the order of Rhizobium inoculation combined to phosphorus fertilizer. Similarly, rhizobium strain and P fertilizers as well as their interaction effect significantly affected the total nitrogen of the soil. This is because of N-fixed biologically by microorganism (Chimdi *et al.*, 2022).

Table 6: Interaction effect of phosphorus and rhizobia on Organic carbon and Total nitrogen content of soil.

Rhizobia inoculation	Phosphorus (kg/ha)					
	Organic carbon			Total nitrogen		
	0	20	40	0	20	40
With	2.78 ^a	2.66 ^{ab}	2.91 ^a	0.24 ^a	0.23 ^{ab}	0.25 ^a
Without	2.02 ^b	2.49 ^{ab}	2.84 ^a	0.17 ^c	0.21 ^b	0.24 ^a
LSD	0.6712			0.0349		
CV (%)	14.07			8.48		

Where:-LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation; Means in columns followed by the same letters are not significantly different at 5% level of significance.

4.1.7. Available phosphorus

The analysis of variance showed that the main effects of phosphorus ($P < 0.001$) and vermicompost ($P < 0.05$) significantly influence the available phosphorus content of the soil.

While the main effect of rhizobia was not significant.

Similarly, two factor interaction of phosphorus x rhizobia, rhizobia x vermicompost and three factor interaction of phosphorus x rhizobia x vermicompost were not significant. On the other hand two factor interaction of phosphorus x vermicompost significantly ($P < 0.01$) influence the available phosphorus content of the soil. The highest residual phosphorus (13.88 mg kg^{-1}) was obtained from the plot that received interaction of the highest 40 kg P ha^{-1} with 8 t/ha vermicompost whereas the lowest residual phosphorus (7.01 mg kg^{-1}) was recorded from the control plot (Table 7).

Except for the control plot, the values of available phosphorus obtained after the trial were higher than those recorded before the trial. The result recorded from this study agreed with that of (Bekele *et al.*, 2018). The available P of the soil varied from 4.5 to $8.3 \text{ mg} \cdot \text{kg}^{-1}$ after incubation. The highest available P was obtained when chemical P ($60 \text{ kg} \cdot \text{P} \cdot \text{ha}^{-1}$), lime ($2 \text{ tons} \cdot \text{ha}^{-1}$), and VC ($5 \text{ tons} \cdot \text{ha}^{-1}$) were applied in combination. In addition, the highest increment (3.98 mg kg^{-1}) was resulted from the application of P at the rate 40 kg P ha^{-1} , whereas the lowest increment (1.42 mg kg^{-1}) was resulted from 10 kg P ha^{-1} application (Gidago *et al.*, 2011). The highest available phosphorus obtained from vermicompost and NPS fertilizer could be due to release of phosphorus from vermicompost and supply of phosphorus to the soil by NPS fertilizer (Emamu & Wakgari, 2021). Similarly, Nitrogen (N), phosphorus (P), Potassium (K), and other micronutrients become more available due to microbial activities in VC. Because VC is recognized as an effective plant growth promoter (Rehman *et al.*, 2023).

Table 7: Interaction effect of phosphorus x vermicompost on available phosphorus content of soil.

Phosphorus (kg/ha)	Vermicompost (ton/ha)		
	0	4	8
0	7.01 ^{cde}	6.47 ^e	6.68 ^{de}
20	9.43 ^{bc}	13.49 ^a	10.45 ^b
40	9.08 ^{bcd}	10.80 ^b	13.88 ^a
LSD			2.5789
CV (%)			11.59

Where:-LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation; Means in columns followed by the same letters are not significantly different at 5% level of significance.

4.2. Effects of Phosphorus, Vermicompost and Rhizobia on Phonological and Growth Parameters of Common Bean

4.2.1. Days to 90% physiological maturity

The analysis of variance illustrated that only the main effects of Rhizobium significantly ($P < 0.05$) affected days to 90% physiological maturity. While the main effect of phosphorus and vermicompost and two factor interactions of phosphorus x Rhizobium, phosphorus x vermicompost, Rhizobium x vermicompost did not affect days to 90% physiological maturity. Similarly, the three-factor interaction effect of Rhizobium x phosphorus x vermicompost did not significantly influence days to physiological maturity.

The shortest days (80.22) to physiological maturity was recorded in non-inoculated plants while the longest days (82.11) to reach physiological maturity was observed in the inoculated treatment (Table 8). The results showed that common bean plants in the control treatment attained 90% of physiological maturity earlier than the inoculated treatments. Rhizobia inoculation resulted in significantly delayed physiological maturity.

Legumes do not require nitrogen that has been industrially fixed. On the other hand, improve the fertility of the soil by adding up to 30 kg of nitrogen per hectare (Ravikumar, 2012). So, inoculation increase nitrogen and nitrogen shows a significant increase in the number of days required to reach physiological maturity (Table 8). This might be by the role of nitrogen in promoting vegetative growth. This is in agreement with the results of (Tadesse and Dechassa, 2017) who reported that delaying of plant maturity because of nitrogen in promoting vegetative and lush growth. This is further corroborated by the results of (Adane, 2023) who reported that the delayed maturity of Faba bean due to the N fixed by seed inoculation with rhizobium strain promoted vegetative growth of the crop, which let to delayed vegetative growth because of boosting plant growth-promoting enzymes, hormones and auxins, maintaining and improving N levels through N fixation.

Table 8: Effect of rhizobium inoculation on 90% physiological maturity.

Rhizobium	90% physiological maturity
With	82.11 ^a
Without	80.22 ^b
LSD0.05	1.834
CV%	4.08

Where:- LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation; Means in columns followed by the same letters are not significantly different at 5% level of significance.

4.2.2. Days to 50% flowering

Days to 50% flowering was significantly affected by the main effects of phosphorus ($P < 0.05$), rhizobia ($P < 0.001$) and vermicompost ($P < 0.001$) significantly. While two factor interaction effects of phosphorus x vermicompost, rhizobia x vermicompost and phosphorus x rhizobia were not significant to days to 50% flowering.

On the other hand three way interaction terms of phosphorus x rhizobia x vermicompost significantly ($P < 0.01$) influence Days to 50% flowering. The longest days (50.66) to 50% flowering was recorded in the plants treated with 4 t ha⁻¹ Vermicompost, 20 kg P ha⁻¹ and Rhizobium inoculated treatments while The shortest days (46.66) to reach Days to 50% flowering was observed in the application of 0 Vermicompost t ha⁻¹, 0 kg P ha⁻¹ and without Rhizobium inoculated treatments (Table 9). The results showed that common bean plants in the control treatment attained Days to 50% flowering earlier than plants in the other treatments. The prolonged in days to flowering due to organic, inorganic and biofertilizer may be attributed role of nitrogen from rhizobia and vermicompost plays in promoting vegetative growth. This result is in line with (Tadesse and Dechassa, 2017) when the nitrogen supply was increased to 46 kg N ha⁻¹, the days to 50% flowering was delayed significantly. Similarly, The longest day to fowering (44.75) was achieved with a 5 t FYM·ha⁻¹ rate (Tadesse *et al.*, 2022). Also corroborated with (Tadesse, 2017), the synergic effects of the organic, inorganic and bio-fertilizers in stimulating cell growth and delaying vegetative growth resulted in the prolonged 50% flowering date.

4.2.3. Plant height

The analysis of variance illustrated that the main effect of phosphorus ($P < 0.001$) and vermicompost ($P < 0.05$) significantly influenced the plant height. Similarly interaction effect of phosphorus x Rhizobium, phosphorus x vermicompost, Rhizobium x vermicompost and phosphorus x Rhizobium x vermicompost significantly ($P < 0.001$) influence the plant height of the crop. On the other hand the main effect of Rhizobium did not influence the plant height of the crop.

A significant increase in plant height was attained with all treatments over control. But the highest number was observed from inorganic fertilizer (phosphorus) application and followed by organic, inorganic and bio-fertilizer applications. Application of P very highly significantly ($P < 0.001$) improved plant height of common bean over control. Where the highest plant height (89.00 cm), (74.8cm) was recorded with 40kg P ha^{-1} and $40\text{ kg P ha}^{-1} + 8\text{ ton/ha}$ vermicompost + rhizobium inoculated respectively. While the lowest plant height (38.3 cm) was recorded from control (Table 9). The result indicated that applying organic, inorganic and bio-fertilizers to the soil considerably improved the nutrient availability. The result of this study agree with that of Hordofa Sigaye *et al* (2020), who reported that the maximum plant height of bean was recorded in response to the application of different levels of phosphorus. Debela *et al* (2021) also report the same result with this study. The effect of NPS rate showed significant ($p < 0.01$) effect on plant height. Increased plant height with enriched vermicompost, phosphorus plus rhizobium resulted from better nodulation, better nitrogen uptake, increased phosphorus and increased soil fertility (Khalid *et al.*, 2023).

4.2.4. Number of primary branches per plant

The analysis of variance illustrated that the main effect of phosphorus and interaction effect of phosphorus x vermicompost, phosphorus x Rhizobium, Rhizobia x vermicompost, three way interaction of phosphorus x vermicompost x Rhizobium showed significant ($P < 0.05$) influenced on the number of primary branches. On the other hand the main effect of vermicompost and Rhizobium inoculated did not showed significant effect on the number of primary branches.

The maximum number of primary branches per plant was (9.6) produced by plants treated with the combined application of phosphorus 20 kg P ha⁻¹ and 4 t ha⁻¹ vermicompost. The minimum number of branches per plant (3.73) was produced at the rate of phosphorus 0 kg P ha⁻¹ combined with 0 t of vermicompost ha⁻¹ and Rhizobium un-inoculated or control (Table 9). Phosphorus also interacted with vermicompost and Rhizobium inoculated to influence branches production. Tadesse *et al* (2022), also reported the same result with this study. The results revealed that interactions between NPSB and FYM had a significant effect on the number of primary branches per plant.

Table 9: Interaction effect of phosphorus, rhizobia and vermicompost on plant height (cm), number of primary branch (number), Days to 50% flowering (number).

Treatment	PLH	NPB	50% FD
Control	38.83 ^f	3.73 ^g	46.66 ^e
HB+I	62.66 ^{cd}	7.16 ^{de}	49.33 ^{bc}
4Vc-I	57.8 ^d	7.03 ^{def}	48.66 ^c
8Vc-I	64.63 ^{cde}	7.20 ^d	48.33 ^c
4Vc+I	69.30 ^{bc}	7.80 ^{cd}	49 ^{cd}
8Vc+I	60.16 ^{de}	7.46 ^d	49 ^{cd}
20P-I	84.66 ^a	8.00 ^{bcd}	48 ^d
40P-I	89.00 ^a	9.33 ^{abc}	48 ^d
20P+I	60.16 ^{de}	7.66 ^d	48.33 ^{cd}
40P+I	57.50 ^{de}	7.66 ^d	48 ^d
20P+4Vc-I	63.43 ^{cde}	9.60 ^a	48.33 ^{cd}
20P+4Vc+I	67.83 ^{bcd}	7.66 ^d	50.66 ^a
20P+8Vc-I	57.06 ^{de}	6.73 ^{def}	49 ^{cd}
20P+8Vc+I	59.36 ^{de}	7.60 ^d	50.33 ^{ab}
40P+4Vc-I	63.90 ^{cde}	7.66 ^d	49 ^{cd}
40P+4Vc+I	58.36 ^{de}	5.46 ^f	50.33 ^{ab}
40P+8Vc-I	63.86 ^{cde}	5.60 ^e	49 ^{cd}
40P+8Vc+I	74.80 ^b	7.60 ^d	50.33 ^{ab}
LSD0.05	7.7458	1.5748	1.26
CV (%)	7.29	13.04	1.55

Where:- LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation; Means in columns followed by the same letters are not significantly different at 5% level of significance. PLH, plant height, NPB number of primary branch, 50%FD= 50% flowering date.

4.3. Effects of Phosphorus, Vermicompost and Rhizobia on Nodulation Parameters of Common Bean

4.3.1. Total number of nodules

The analysis of variance showed that the main effects of phosphorus ($P < 0.05$), vermicompost, Rhizobium and two factor interaction of Rhizobium x vermicompost ($P < 0.0001$), phosphorus x vermicompost ($P < 0.05$) significantly influenced the total number of nodules produced per plant. Similarly, the three-factor interaction of phosphorus x vermicompost x Rhizobium significantly ($P < 0.05$), influenced the total number of nodules. On the contrary, the two-factor interactions of phosphorus x Rhizobium did not significantly affect the total number of nodules.

The result in (Table 10) showed significant interaction between Rhizobium inoculated, vermicompost and phosphorus fertilizer application on total number of nodules per plant. Nodule number was significantly higher in inoculated plants and increased phosphorus rates. The highest numbers of total nodules per plant (74.66) were recorded at 40 kg P ha⁻¹ and Rhizobium inoculated followed by (70) with rhizobia inoculated. While the lowest number of nodules per plant (32) was recorded in the control treatment (Table 10).

The result of this study was similar with Nigatu (2017). He report that, the highest (138.3) number of nodules per plant of faba bean were recorded when the seeds were inoculated with Rhizobium strain at fertilizer rate of 69 kg P ha⁻¹. Similarly, Dela *et al.*, (2023) reported that, application of NPSB fertilizer and inoculation of Rhizobia strain on common bean had significant effect on the total number of nodules at Sodo Zuria Southern Ethiopia.

Asante *et al.*, (2020), also agree with this study. Report that, the groundnut varieties responded differently to the combined applications of each of the two inoculant strains with P in terms of nodule number. Oli *et al.*, (2020), report that, the highest number of total nodules (68.53) was observed from the interaction effect of Rhizobium inoculation with NPS rate of 100 kg ha⁻¹. According to Gedamu *et al.*, (2021) and Khaitov *et al.*, (2020), significant effect of Inoculation with rhizobial strains on faba bean and chickpea respectively. The reason of this result might be the addition of efficient phosphorus fertilizer. Deficiency of phosphorus can affect symbiotic N₂ fixation in bean more than in other legume crops. Plants deficient in P had a decreased nodule number and decreased nodule biomass when grown in soil (Tang *et al.*, 2001). Additionally inoculated bacteria strain had good nodulation inducing capacity over the native soil rhizobium population (Meleta, 2019).

4.3.2. Effective number of nodules

The analysis of variance showed that the main effects of phosphorus ($P < 0.05$), Rhizobium and vermicompost were significantly ($P < 0.001$) influenced on the effective number of nodules per plant. Similarly, two-factor interaction of phosphorus x Rhizobium, Rhizobium x vermicompost and three-factor interaction of phosphorus x vermicompost x Rhizobium had significant effects on these parameters. On the other hand two-factor interaction of phosphorus x vermicompost had no significant influenced on the effective number of nodules. The highest number of effective nodules per plant (41) was resulted from inoculated with Rhizobium which was followed by the application of 40 kg P ha⁻¹ inoculated with Rhizobium (40.66) while the lowest number of effective number of nodules per plant (14.83) was recorded in the control treatment (Table 10).

The reason behind this result may be due to best rhizobia and efficient phosphorus fertilizer. In agreement with this result, Dela *et al.*, (2023) report that, the plot that received a combined application of 150 kg ha⁻¹ of NPSB fertilizer with inoculation of Rhizobium had the largest number of effective nodules (75.13), whereas the control plot had the lowest (30). Similarly, Oli *et al.*, (2020), also get the same result to this study. The highest number of effective nodules (19.32) was observed from the interaction effect of NPS rate of 100 kg ha⁻¹.

4.3.3. Nodule dry weight

The analysis of variance demonstrated that the main effects of phosphorus ($P < 0.05$), vermicompost and Rhizobium was very highly significantly ($P < 0.001$) affected nodule dry weight per plant. The two-factor interactions of Rhizobium x vermicompost ($P < 0.001$), phosphorus x Rhizobium and phosphorus x vermicompost also had significant ($P < 0.05$) effect in this parameter. Similarly the three-factor interaction of phosphorus x vermicompost x Rhizobium significantly ($P < 0.05$) affected the nodule dry weight of the crop.

The highest nodule dry weight (318.16mg/plant) was recorded from plots treated with phosphorus 40 kg P ha⁻¹ plus rhizobium inoculated and followed by plot treated with rhizobia inoculated (226.91mg/plant) (Table 10). Whereas the lowest nodule dry weight (115.03 mg/plant) was obtained from control plots. This result corroborates with Akpalu (2014) the increase in growth of nodules was equivalent to increased nodule dry weight of the plants. Therefore, on 28 days after planting soybean, phosphorus with rhizobia (+P/+I) had a significant increase in dry weight of 1.3g/plt. This might be because of the positive role that P₂O₅ plays in enhancement of photosynthesis and promoting nodulation in plants (Meleta, 2019).

4.4. Effects of Phosphorus, Vermicompost and Rhizobia on Biological Nitrogen Fixation (BNF)

Fixed nitrogen and %Ndfa

The analysis of variance demonstrated that the main effects of vermicompost ($P < 0.05$), and Rhizobium ($P < 0.001$) was significantly affect fixed nitrogen and %Ndfa. Fixed nitrogen had significantly ($P < 0.05$) affected by interactions of Rhizobium x vermicompost. While %Ndfa was significantly affected by interactions of Rhizobium x vermicompost and phosphorus x vermicompost. Similarly, the three-factor interaction of phosphorus x vermicompost x Rhizobium significantly ($P < 0.001$) affect fixed nitrogen and %Ndfa. But the main effect of phosphorus, two-factor interaction of phosphorus x Rhizobium and phosphorus x vermicompost (fixed nitrogen) did not affect significantly.

The highest fixed nitrogen (54.42 kg/ ha) and %Ndfa (52.42%) was recorded from plots treated with phosphorus 20 kg P ha⁻¹, 8 t/ha vermicompost plus rhizobium inoculation. Whereas the lowest fixed nitrogen (16.12 kg/ha) and %Ndfa (24.66%) was obtained from control plots (table 10). According to Shimelis and Senait (2023), the highest fixed nitrogen (66.9 kg ha⁻¹) and %Ndfa (52.46%) was from the interaction effect of 5 t ha⁻¹ vermicompost with 30kg ha⁻¹ phosphorus at Dore district. Similarly, higher %Ndfa resulted in significantly larger BNF in phosphorus plus inoculation treatments compared with the control (Raji *et al.*, 2019). Meleta (2019) also report that Rhizobium inoculation and phosphorus application rate significantly influenced the amount of biologically fixed N₂ and % Ndfa. This might be due to the P increases the number and size of nodules and the amount of nitrogen assimilated per unit weight of nodules, increasing the percent and total amount of nitrogen (Basher *et al.*, 2011).

Moreover, it might be due to the inoculation of seed with rhizobium inoculums probably attributed to the enhanced availability of N through BNF for vegetative growth of the plants (Ali *et al.*, 2008).

Table 10: Interaction effect of phosphorus, rhizobia and vermicompost on nodule number per plant(number), effective number of nodule (number), nodule dry weight (mg), fixed nitrogen (kg/ha) and %Nd_{fa}.

Treatment	NNPP	ENN	NDW	Fixed N	%Nd _{fa}
Control	30.83 ⁱ	14.83 ^j	115.03 ^{cd}	16.1260 ^e	24.66 ^f
HB+I	70.0 ^{ab}	41.00 ^a	226.91 ^b	49.50 ^{ab}	50.17 ^a
4Vc-I	40.06 ^{efgh}	17.30 ^{ij}	124.00 ^{cd}	42.05 ^{bc}	46.17 ^{abc}
8Vc-I	41.23 ^{efgh}	19.93 ^{gh}	135.13 ^{cd}	35.81 ^{cd}	42.05 ^{cde}
4Vc+I	45.16 ^{def}	25.16 ^{def}	151.50 ^{cd}	30.24 ^d	37.80 ^{cde}
8Vc+I	41.56 ^{efgh}	24.00 ^{fgh}	136.98 ^{cd}	49.81 ^{ab}	50.14 ^{ab}
20P-I	43.83 ^{defg}	22.66 ^{fgh}	144.33 ^{cd}	27.91 ^d	35.87 ^{cde}
40P-I	49.66 ^{cd}	24.66 ^{efg}	139.00 ^{cd}	34.72 ^{cd}	41.24 ^{cde}
20P+I	64.16 ^b	34.33 ^b	159.33 ^{cd}	37.41 ^{cd}	42.87 ^{bcd}
40P+I	74.66 ^a	40.66 ^a	318.16 ^a	44.24 ^{abc}	47.32 ^{abc}
20P+4Vc-I	36.43 ^{ghi}	17.46 ^{ij}	137.66 ^{cd}	26.92 ^{de}	35.19 ^e
20P+4Vc+I	53.93 ^c	30.00 ^{bcd}	141.16 ^{cd}	50.76 ^{ab}	50.68 ^a
20P+8Vc-I	37.26 ^{ghi}	20.50 ^{fghi}	135.56 ^{cd}	26.98 ^{de}	35.50 ^e
20P+8Vc+I	41.33 ^{efgh}	20.00 ^{ghi}	137.33 ^{cd}	54.42 ^a	52.42 ^a
40P+4Vc-I	34.33 ^{hi}	17.00 ^{ij}	126.13 ^{cd}	-	-
40P+4Vc+I	52.86 ^c	30.56 ^{bc}	144.65 ^{cd}	-	-
40P+8Vc-I	39.26 ^{efgh}	19.16 ^{hij}	132.96 ^{cd}	-	-
40P+8Vc+I	47.00 ^{cde}	29.33 ^{cde}	143.46 ^{cd}	-	-
LSD0.05	7.574	4.9943	37.864	11.245	7.289
CV (%)	9.73	12.07	14.93	17.80	10.26

Where:- LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation; Means in columns followed by the same letters are not significantly different at 5% level of significance. NNPP =nodule number per plant, ENN = effective number of nodule, NDW= nodule dry weight, FixedN= fixed nitrogen.

4.5. Effects of Phosphorus, Vermicompost and Rhizobia on Yield and Yield Components

Common Bean

4.5.1. Number of pods per plant (number)

The analysis of variance showed that the main effect of vermicompost and three-factor interaction of phosphorus x vermicompost x Rhizobium significantly ($P < 0.001$) influenced on the number of pods produced per plant. Similarly, two-factor interaction of phosphorus x Rhizobium and phosphorus x vermicompost influence significantly ($P < 0.05$) the number of pods produced per plant. While main effect of Rhizobium, phosphorus two factor interaction of Rhizobium x vermicompost did not influence on number of pods per plant. The results in (Table 11) showed a significant interaction between Rhizobium inoculated phosphorus and vermicompost levels on the number of pods per plant. The lowest number of pods per plant (6.16) was recorded in control whereas the highest number of pods per plant (16) was recorded at the rate of 20 kg P ha⁻¹ Rhizobium inoculated and combined with 8 vermicompost t ha⁻¹ (Table 11).

The result of this study confirms the result of Debela *et al.*, (2021) who confirmed that, the three factor interaction of NPS × Rh × VC was significant ($p < 0.01$) on the number of pods produced per plants. Maximum number of pods per plant (23.95) was recorded with the application of 75% NPK through an inorganic source + 25% N through vermicompost (Barcchiya and Kushwah, 2017). the finding of Tadesse *et al.*, (2022) assure that, with a mean number of pods per plant of 17.35, the highest (18.95) number of pods per plant was obtained with a combined application of 150 kg NPSB·ha⁻¹ and 2.5 t FYM·ha⁻¹, followed by a single application of 5 t FYM·ha⁻¹.

The reason behind this result might be the combination of organic and inorganic fertilizers improves soil physical properties, which provide health and favourable soil conditions to enhance nutrient use efficiency (Bari *et al.*, 2016). The increase in number of pods with the increased P levels might possibly be due to adequate availability of P which might have facilitated the production of primary branches and plant height which might, in turn, have contributed to the production of higher number of total pods (Negash *et al.*, 2020).

4.5.2. Number of seeds per pod (number)

The main effects of phosphorus and Rhizobium significantly ($P < 0.05$) influence on the number of seeds per pod while vermicompost did not affect significantly. Furthermore, the two-factor interaction of phosphorus x Rhizobium and Rhizobium x vermicompost did not significantly influence the number of seeds per pod produced by the plant. while the interaction of phosphorus x vermicompost ($P < 0.001$) very highly significantly affected this parameter. The three-factor interaction of phosphorus x vermicompost x Rhizobium also significantly ($P < 0.05$) affected the number of seeds per pod produced by the plant.

The main and interaction effects of organic, inorganic and bio-fertilizers influenced the number of seeds produced per plant (Table 11). Increasing the rate of phosphorus and vermicompost significantly enhanced the number of seeds produced. Thus, significantly higher number of seeds was produced at rate of phosphorus and vermicompost increased. The highest number of seeds per pod of common bean (5.4) and (5.36) was obtained from plots obtained phosphorus, and vermicompost 8 t ha^{-1} with 40 kg P ha^{-1} respectively, whereas the lowest seeds per pod (3.46) was recorded from un-inoculated plants, 0 kg P ha^{-1} , 0 t ha^{-1} vermicompost (control).

Additionally, at combined rates of organic, inorganic and bio-fertilizers also got significantly higher number of seeds (5.33). this result was supported by Elka and Laekemariam (2020), the number of seeds per pod were significantly ($p < 0.01$) affected by the main effects of NPS and OF (organic fertilizer) application.

4.5.3. Aboveground biomass yield

The analysis of variance showed that the main effects of phosphorus, vermicompost and Rhizobium were significant ($P < 0.001$) influenced on above ground biomass yield. The two-factor interaction of phosphorus x vermicompost ($P < 0.01$), phosphorus x Rhizobium ($P < 0.001$) and Rhizobium x vermicompost ($P < 0.05$) significantly influenced aboveground biomass yield. Similarly, the three factor interaction of phosphorus x vermicompost x Rhizobium had significantly ($P < 0.001$) affected the aboveground biomass of common bean.

Increasing biomass was observed in response to the application of higher phosphorus and Rhizobium inoculated combined with the increasing rates of vermicompost. Application of 40 kg P ha⁻¹ + 8 t vermicompost ha⁻¹ and Rhizobium inoculated showed maximum (6728.39 kg ha⁻¹) biomass. However, the minimum (3454.30 kg ha⁻¹) biomass was measured at the combined application of 0 kg P ha⁻¹ + 0 t vermicompost ha⁻¹ and Rhizobium un- inoculated (Table 11).

The results of the present study are in conformity with the work of Lishan *et al.*, (2023), the applications of TSP and manure at all rates resulted in significantly higher dry matter yield than the controls. Tadesse *et al.*, (2022), get the highest biomass yield (6998 kg·ha⁻¹) from combined application of 150 kg NPSB·ha⁻¹ with 5 t FYM·ha⁻¹ which is similar with this study.

Debela *et al.*, (2021), Elka and Laekemariam, (2020) report maximum aboveground biomass (8953 kg ha^{-1}), (45.2 g/plant) from combined effect of $100 \text{ kg NPS ha}^{-1}$ combined $2 \text{ tons vermicompost ha}^{-1}$, $150 \text{ kg NPS ha}^{-1}$ and 5 t ha^{-1} OF (organic fertilizer) respectively. The increase in the aboveground biomass at the highest rates of P, rhizobium inoculated and VC might be due to the increase in nutrient availability which increases plant growth and development.

4.5.4. Harvest index

The analysis of variance showed that the main effects of phosphorus, Rhizobium and vermicompost were significantly ($P < 0.001$), ($P < 0.05$) influenced on harvest index of common bean respectively. The two-factor interaction of phosphorus x vermicompost ($P < 0.01$) and phosphorus x Rhizobium ($P < 0.001$) significantly influenced the harvest index of the crop. Similarly, the three factor interaction of phosphorus x vermicompost x Rhizobium had significant ($P < 0.05$) effect on harvest index. While the two-factor interaction of Rhizobium x vermicompost had no significant effect on harvest index.

The maximum harvest index (73.71%) was obtained from the application of phosphorus 20 kg P ha^{-1} + 4 t ha^{-1} vermicompost whereas the minimum (50.08%) was from the control (Table 11). The analysis of variance showed the existence of highly significant ($P < 0.01$) differences on harvest index for the main effects of TSP and manure. The application of TSP at rate 100 kg ha^{-1} resulted in the highest (0.52) harvest index. This finding revealed the vital role of P for grain development while manure contributed to vegetative growth (Lishan *et al.*, 2023). This might be the result of the plant having more access to important nutrients, which boosted early root development and cell multiplication.

This, in turn, led to increased absorption of other nutrients from deeper soil layers, which in turn produced an increased harvest index (Debela *et al.*, 2021).

Table 11: Interaction effect of phosphorus, rhizobia and vermicompost on number of pod per plant (number), number of seed per pod (number), above ground dry biomass (kg/ha) and harvest index (%).

Treatment	NPPP	NSPP	AGDB	HI (%)
Control	6.16 ^f	3.46 ^e	3454.30 ^j	50.08 ^{igh}
HB+I	12.33 ^{cde}	4.66 ^{cd}	4876.54 ^g	50.66 ^{fgh}
4Vc-I	12.73 ^{cde}	4.40 ^d	5246.91 ^{ef}	55.33 ^{defg}
8Vc-I	12.53 ^{cde}	5.40 ^a	5000.00 ^{fg}	44.62 ^h
4Vc+I	10.86 ^e	5.13 ^{abc}	4691.35 ^{gh}	57.84 ^{def}
8Vc+I	13.20 ^{bcd}	4.90 ^{abcd}	5370.37 ^{de}	51.84 ^{efgh}
20P-I	10.33 ^{ef}	5.13 ^{abc}	3641.97 ^j	72.98 ^a
40P-I	13.83 ^{abcd}	5.36 ^a	3703.70 ^j	71.69 ^{ab}
20P+I	6.83 ^f	5.33 ^{ab}	4444.44 ^{hi}	67.96 ^{abc}
40P+I	8.00 ^f	5.26 ^{ab}	5370.37 ^{de}	59.81 ^{cde}
20P+4Vc-I	15.66 ^{ab}	5.00 ^{abc}	4135.80 ⁱ	73.71 ^a
20P+4Vc+I	15.73 ^{ab}	4.76 ^{bcd}	6172.83 ^b	48.09 ^{gh}
20P+8Vc-I	10.93 ^e	5.06 ^{ab}	4938.27 ^{fg}	63.73 ^{bcd}
20P+8Vc+I	16.00 ^a	5.10 ^{abc}	5679.01 ^{cd}	55.41 ^{defg}
40P+4Vc-I	11.40 ^{de}	5.06 ^{abc}	5740.74 ^c	60.18 ^{cde}
40P+4Vc+I	11.86 ^{de}	5.33 ^{ab}	6604.93 ^a	53.30 ^{efg}
40P+8Vc-I	14.66 ^{abc}	4.76 ^{bcd}	4691.35 ^{gh}	67.17 ^{abc}
40P+8Vc+I	12.33 ^{cde}	5.16 ^{abc}	6728.39 ^a	54.12 ^{efg}
LSD0.05	2.6924	0.5815	338.48	8.5277
CV (%)	13.55	7.06	4.05	8.73

Where:- LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation; Means in columns followed by the same letters are not significantly different at 5% level of significance. NPPP = number of pod per plant, NSPP = number of seed per pod, AGDB = above ground dry biomass, HI= harvest index.

4.5.5. Thousand seed weights

Analysis of variance revealed that the main effects of phosphorus and two way interaction of phosphorus x vermicompost significantly ($P < 0.05$) influenced thousand seed weights of common bean. While the main effects of Rhizobium and vermicompost had no significant effect on thousand seed weights. Similarly, two way interaction of phosphorus x Rhizobium, Rhizobium x vermicompost and three-factor interaction of phosphorus x Rhizobium x vermicompost had no significant effect on thousand seed weights of common bean.

The application of phosphorus with vermicompost significantly increased thousand seed weight common bean (Table 12). The highest thousand seed weight (246.67 g) was obtained from application of phosphorus at 40 kg P ha⁻¹ followed by combined application of vermicompost at 8 t ha⁻¹ and phosphorus at 40 kg P ha⁻¹ (234.06 g). Whereas the lowest (200.81g) thousand seed weight was obtained from the control plot (Table 12). In consistent with the present findings, The maximum 1000 seed weight (230.7 gm) was obtained from the application of 40 kg of P ha⁻¹ (Hordofa Sigaye *et al.*, 2020). Similarly, Elka and Laekemariam, (2020) reported high thousand seed weight from the interaction effect of NPS and OF (organic fertilizer). According to Tadesse *et al.*, (2022) the maximum seed weight (27.5 g) was recorded when 100 kg NPSB and 2.5 t FYM (farm yard manure) were applied together. Maximum thousand seed weight from P application might be due to the supply of phosphorus that increase the formation of seed (Debela *et al.*, 2021).

Table 12: Interaction effect of phosphorus x vermicompost on thousands seed weights (g).

Phosphorus (kg/ha)	Vermicompost (ton/ha)		
	0	4	8
0	200.81 ^c	220.84 ^{abc}	218.35 ^{abc}
20	232.58 ^{ab}	209.92 ^{bc}	211.53 ^{bc}
40	246.67 ^a	220.06 ^{abc}	234.06 ^{ab}
LSD			29.596
CV (%)			5.79

Where:-LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation; Means in columns followed by the same letters are not significantly different at 5% level of significance.

4.5.6. Grain yield

The analysis of variance showed that the main effects of phosphorus, vermicompost and Rhizobium Significantly ($P < 0.001$) influenced grain yield. Also the two-factor interaction of phosphorus x vermicompost and Rhizobium x vermicompost ($P < 0.05$) significantly influenced grain yield. But common bean grain yield was not influenced by two-factor interaction of phosphorus x Rhizobium and three-factor interaction of phosphorus x Rhizobium x vermicompost. There was a significant variation on grain yield by the interaction effect of phosphorus and vermicompost (Table 13). A combination of phosphorus and vermicompost resulted in higher grain yield than that with control treatment. The highest grain yield ($3487.65 \text{ kg ha}^{-1}$) was recorded at the rate of phosphorus 40 kg P ha^{-1} and $4 \text{ t vermicompost ha}^{-1}$ followed by phosphorus 40 kg P ha^{-1} and $8 \text{ t vermicompost ha}^{-1}$ ($3395.06 \text{ kg ha}^{-1}$) whereas the lowest grain yield ($2098.7 \text{ kg ha}^{-1}$) was recorded from control plot (Table 13).

The results of the present study was in conformity with the work of Elka and Laekemariam, (2020) indicated that application of 150 kg NPS ha⁻¹ and 2.5 t organic fertilizer ha⁻¹ significantly resulted the highest grain yield (4.16 t/ha). Similarly, the maximum grain yield (2765 kg·ha⁻¹) was achieved with an integrated application of 100 kg NPSB fertilizer·ha⁻¹ and 5 t FYM·ha⁻¹, followed by an integrated application of 100 kg NPSB fertilizer·ha⁻¹ and 2.5 t FYM·ha⁻¹ with grain yield of 2628 kg·ha⁻¹ (Tadesse *et al.*, 2022). In the same way, the application of 100 kg ha⁻¹ TSP in combination with 5t ha⁻¹ manure resulted in the highest grain yield of 3.40 t ha⁻¹ (Lishan *et al.*, 2023). This increased yield from applying mineral fertilizer and vermicompost together may be due to the presence of growth-promoting substances, various beneficial microorganisms, and macro- and micronutrient availability (Debela *et al.*, 2021).

Table 13: Interaction effect of phosphorus with vermicompost and rhizobia on grain yield of common bean.

Vermicompost (ton/ha)	Phosphorus (kg/ha)			Rhizobia inoculation	
	0	20	40	With	Without
0	2098.7c	2839.50ab	2932.09ab	2901.23 ^{ab}	2345.67 ^b
4	2808.64ab	2993.82ab	3487.65a	3065.84 ^{ab}	3127.57 ^{ab}
8	2499.9bc	3148.14ab	3395.06a	3189.30 ^a	2839.50 ^{ab}
LSD	690.86			782.89	
CV (%)	10.28			14.78	

Where:-LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation; Means in columns followed by the same letters are not significantly different at 5% level of significance.

5. SUMMARY AND CONCLUSION

In Ethiopia, the common bean is a major food crop and a substantial source of revenue. Smallholder farmers cultivate the crop mainly for consumption. Among the fastest growing legume crops, it is an essential part of most Ethiopians' daily diets and their main source of income. However, the national average yield is very low due to a number of abiotic and biotic stresses, soil fertility depletion, use of inappropriate rate of nutrients and application without soil test, and inefficient crop response.

Therefore, a field experiment was conducted at Wulbareg district to study the effect of integrated use of Rhizobium inoculation, vermicompost, and phosphorus fertilizer on yield and yield components of common bean, on selected soil properties and biological nitrogen fixation during the 2022 main cropping season. Factorial combination of three phosphorus rates (0, 20, 40 kg P ha⁻¹), three vermicompost rates (0, 4, 8 ton ha⁻¹) and Rhizobium inoculation (with and without) were laid out in randomized complete block design (RCBD) with three replications. Soil samples were collected from the experimental field (0-20 cm depth) before planting and after harvest to determine the effect on selected the soil properties. The experimental soil was loam in texture, moderate in bulk density, very strongly acidic in reaction, low in organic carbon, low in total nitrogen , low in available phosphorus and high in cations exchange capacity of the soil. So, the experimental area has a deficiency of plant nutrients.

The soil physicochemical properties after harvesting showed significant improvement by sole application of vermicompost, rhizobia, phosphorus and their interaction. pH and cations exchange capacity of the soil was significantly affected by the main effect of vermicompost.

The main effect of vermicompost, rhizobia, phosphorus and interaction of rhizobia x phosphorus significantly affect total nitrogen and organic carbon. The main effect of vermicompost and interaction of phosphorus and vermicompost significantly affect bulk density and available phosphorus. Available phosphorus additionally affected by the main effect of phosphorus. The moisture content of soil was significantly affected by main effect of vermicompost and interaction of vermicompost with phosphorus, rhizobia and three way interaction of vermicompost, phosphorus, rhizobia.

Application of phosphorus, vermicompost, rhizobia inoculated and their interaction increased most yield and yield parameters of the common bean compared to the control plots. Phenological and growth parameters (50% flowering date, Plant height, Number of primary branch) were significantly affected by three way interaction of vermicompost, phosphorus and rhizobia and 90% physiological maturity was significantly affected by the main effect of rhizobium inoculation. Similarly, the number of seeds per pod, harvest index, pod number per plant, above ground dry biomass, nodule number, the effective number of the nodule, nodule dry weight, biologically fixed nitrogen and percent of nitrogen derived from the atmosphere significantly affected by three way interaction of vermicompost, phosphorus and rhizobia. Main effect of phosphorus and the interaction of vermicompost and phosphorus significantly influenced thousand seed weight and grain yield of common bean. Grain yield additionally affected by the main effect of rhizobia, vermicompost and their interaction.

So, this finding could create awareness as an integrated application of vermicompost, phosphorus fertilizer and rhizobium inoculation helps to increase crop productivity and improve soil fertility.

Therefore, it is recommended that using integrated application of Rhizobium inoculation, with 8 t/ha vermicompost and 40 kg/ha phosphorus fertilizer application increase nodulation, growth parameter, BNF, yield of common bean production in the study area and selected properties of soil of the study area. So, farmers in the study area can apply bio-fertilizer rhizobia, inorganic fertilizer phosphorus and organic fertilizer vermicompost to enhance income and improve food security. But, since the experiment was conducted only for one season at one location, it has to be repeated over seasons and across different locations to make a conclusive recommendation.

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7. APPENDIXES

Appendix Table 1: Mean squares of ANOVA for growth parameters of common bean as affected by phosphorus fertilizer, rhizobium inoculation and vermicompost.

SV	DF	Mean square			
		90%PM	50%FD	PH	NPB
Rep	2	2.38 ^{ns}	2.46*	13.33 ^{ns}	0.19 ^{ns}
P	2	0.66 ^{ns}	2.24*	401.94***	5.93**
Rh	1	48.16*	17.79***	31.89 ^{ns}	0.24 ^{ns}
VC	2	0.22 ^{ns}	9.79***	70.04*	1.15 ^{ns}
PxRh	2	12.66 ^{ns}	0.24 ^{ns}	459.56***	6.22**
PxVC	4	21.31 ^{ns}	0.49 ^{ns}	428.31***	8.42***
RhxVC	2	24.22 ^{ns}	0.12 ^{ns}	322.87***	5.68**
PxRhxCVC	4	4.47 ^{ns}	2.32**	485.64***	4.73**
Error	34	373.88	0.58	21.79	0.9
CV%		4.08	1.55	7.29	13.04

The sign ns, *, ** and *** indicates; non-significance different ($P > 0.05$), Significance difference ($P \leq 0.05$), highly significant difference if ($P < 0.01$) and very highly significant difference ($P < 0.001$) respectively, DF =degree of freedom, Rep =replications, P= phosphorus, Rh= rhizobia, VC = vermicompost, CV= coefficient of variance, 90%PM= 90% physiological maturity, 50%FD= 50% flowering date, PH= plant height, NPB= number of primary branch.

Appendix Table 2: Mean squares of ANOVA for nodulation parameters and biological nitrogen fixations as affected by phosphorus, rhizobium inoculation and vermicompost

SV	DF	Mean square				
		NNPP	EFNN	NDW	FN	%Ndfa
Rep	2	23.12 ^{ns}	29.76*	44.31 ^{ns}	1.415 ^{ns}	1.91 ^{ns}
P	2	111.39**	53.74**	3045.66**	12.02 ^{ns}	14.14 ^{ns}
Rh	1	3163.27***	1718.16***	22777.21***	2402.33***	1071.76***
VC	2	1040.89***	310.05***	13021.57***	165.14*	78.91*
PxRh	2	11.62 ^{ns}	38.92*	4535.51**	106.95 ^{ns}	39.26 ^{ns}
PxVC	4	69.18*	11.71 ^{ns}	3281.23**	96.57 ^{ns}	69.20*
RhxVC	2	663.21***	201***	12690.75***	183.86*	89.99**
PxRhxCVC	4	118.51**	50.48**	2969.41**	721.83***	383.48***
Error	34	20.83	9.05	520.69	1167.21	490.41
CV%		9.73	12.07	14.93	17.8	10.2

*The sign ns, *, ** and *** indicates; non-significance different ($P > 0.05$), Significance difference ($P \leq 0.05$), highly significant difference if ($P < 0.01$) and very highly significant difference ($P < 0.001$) respectively, DF =degree of freedom, Rep =replications, P= phosphorus, Rh= rhizobia, VC =vermicompost, CV= coefficient of variance, NNPP= nodule number per plant, EFNN= effective number of nodule, NDW= nodule dry weight, FN= fixed nitrogen and %Ndfa= percent of nitrogen derived from atmosphere.*

Appendix Table 3: Mean squares of ANOVA for yield and yield components of common bean as affected by phosphorus, rhizobium inoculation and vermicompost.

SV	DF	Mean square					
		NPPP	NSPP	AGB	HI	SW	GY
Rep	2	2.20 ^{ns}	0.34 ^{ns}	7667.67 ^{ns}	13.56 ^{ns}	712.6 ^{ns}	51440.37 ^{ns}
P	2	7.37 ^{ns}	1.27 ^{**}	2702193.82 ^{***}	706.89 ^{***}	2026.63 ^{**}	2989254.09 ^{***}
Rh	1	0.207 ^{ns}	0.66 [*]	14680333.47 ^{***}	609.13 ^{***}	391.02 ^{ns}	1067545.64 ^{***}
VC	2	77.04 ^{***}	0.17 ^{ns}	8191170.05 ^{***}	171.77 ^{**}	429. ^{ns}	1150739.29 ^{***}
PxRh	2	21.55 ^{**}	0.26 ^{ns}	1463379.39 ^{***}	354.40 ^{***}	727.6 ^{ns}	107326.12 ^{ns}
PxVC	4	16.91 ^{ns}	1.00 ^{***}	333406.09 ^{***}	137.86 ^{**}	1154.15 [*]	141937.26 [*]
RhxVC	2	5.74 ^{***}	0.23 ^{ns}	298793.16 ^{**}	36.86 ^{ns}	203.38 ^{ns}	444546.15 ^{**}
PxRhxCVC	4	31.14	0.54 [*]	1255662.45 ^{***}	90.15 [*]	522.86 ^{ns}	53028.03 ^{ns}
Error	34	2.63	0.12	41610.46	26.41	339.15	44716.10
CV%		13.55	7.06	4.05	8.73	8.3	7.26

The sign ns, *, ** and *** indicates; non-significance different ($P > 0.05$), Significance difference ($P \leq 0.05$), highly significant difference if ($P < 0.01$) and very highly significant difference ($P < 0.001$) respectively, DF =degree of freedom, Rep =replications, , P= phosphorus, Rh= rhizobia, VC =vermicompost,CV= coefficient of variance, NPPP= number of pod per plant, NSPP= number of seed per pod, AGB= above ground biomass, HI= harvest index, SW=seed weight and GY= grain yield.

Appendix Table 4: Mean squares of ANOVA for selected chemical properties of soil as affected by phosphorus, rhizobium inoculation and vermicompost.

SV	DF	Mean square				
		pH	OC	TN	AV.P	CEC
Rep	2	0.12005**	0.237 ^{ns}	0.00176 ^{ns}	13.87*	0.351 ^{ns}
P	2	0.06259 ^{ns}	1.044**	0.00776**	119.89***	0.907 ^{ns}
Rh	1	0.00580 ^{ns}	1.520**	0.01129**	10.87 ^{ns}	0.296 ^{ns}
VC	2	0.12430**	2.341***	0.01739***	19.18*	14.685**
PxRh	2	0.07109 ^{ns}	0.625*	0.00464*	5.37 ^{ns}	0.574 ^{ns}
PxVC	4	0.03451 ^{ns}	0.235 ^{ns}	0.00175 ^{ns}	21.71**	0.407 ^{ns}
RhxVC	2	0.00246 ^{ns}	0.012 ^{ns}	0.00009 ^{ns}	0.42 ^{ns}	4.129 ^{ns}
PxRhxCVC	4	0.03709 ^{ns}	0.129 ^{ns}	0.00096 ^{ns}	5.60 ^{ns}	2.240 ^{ns}
Error	34	0.026	0.17	0.0013	4.47	2.74
CV%		2.93	15.99	15.99	21.8	3.80

The sign ns, *, ** and *** indicates; non-significance different ($P > 0.05$), Significance difference ($P \leq 0.05$), highly significant difference if ($P < 0.01$) and very highly significant difference ($P < 0.001$) respectively, DF =degree of freedom, Rep =replications, , P= phosphorus, Rh= rhizobia, VC = vermicompost, CV= coefficient of variance, OC= organic carbon, TN=total nitrogen, AV.P= available phosphorus and CEC= cation exchange capacity.

Appendix Table 5: Mean squares of ANOVA for selected physical properties of soil as affected by phosphorus, rhizobium inoculation and vermicompost.

SV	DF	Mean square			
		BD	MCR1	MCR2	MCR3
Rep	2	0.0036	6.95ns	13.60ns	1.84ns
P	2	0.0135	1.73ns	4.26ns	48.19**
Rh	1	0.0001	101.73**	85.75**	191.89***
VC	2	0.0972***	62.47**	37.18*	26.91**
PxRh	2	0.0118	8.85ns	1.55ns	19.28*
PxVC	4	0.0384**	24.88*	98.70***	38.42***
RhxVC	2	0.0089	25.03*	38.48*	28.26**
PxRhxCVC	4	0.0154	79.23***	64.31**	50.43***
Error	34	0.0059	7.72	9.46	4.82
CV%		6.5	9.60	14.98	15.49

*The sign ns, *, ** and *** indicates; non-significance different ($P > 0.05$), Significance difference ($P \leq 0.05$), highly significant difference if ($P < 0.01$) and very highly significant difference ($P < 0.001$) respectively, DF =degree of freedom, Rep =replications, P= phosphorus, Rh= rhizobia, CV = coefficient of variance, BD= bulk density, MCR1= moisture content round one, MCR2 = moisture content round two and MCR3= moisture content round two.*

BIOGRAPHICAL SKETCH

The author was born on march 19, 1999, in Dera town, Dodota District, Arsi Zone of the Oromia Regional State from her mother Yebirgual Legese and her father Mohammed Yimer. She attended her elementary school education at Dera Elementary School. She also attended high school and preparatory education at dera Secondary and Preparatory School. After that, she joined Jinka University February 2018 and graduated with a Bachelor of Science in natural resource management in January 2021. After graduation, in August 2021, she was employed as Graduate Assistant I at Jinka University. Then she joined the Graduate program in soil science at Hawassa University in 2021 with the opportunity to pursue her Master's program.







