SCHOOL OF GRADUATE STUDIES COLLEGE OF AGRICULTURE AND NATURAL RESOURCE DEPARTMENT OF PLANT SCIENES

EFFECT OF RHIZOBIUM INOCULATION (MB003) AND NPSB FERTILIZER RATES ON GROWTH YIELD AND YIELD COMPONENTS OF MUNG BEAN (*Vigna radiate* (L.) WILCZEK) VARIETIES IN MISRAK-MESKAN DISTRICT EASTERN GURAGE ZONE

MSc. THESIS

BY

MOHAMMED WULCHAFO BADKARO

MAY, 2024
WOLKITE, ETHIOPIA

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THESIS SUBMITTED TO THE DEPARTMENT
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MASTER OF SCIENCE IN AGRONOMY

BY

MOHAMMED WULCHAFO BADKARO

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APPROVAL SHEET

WOLKITE UNIVERSITY

POSTGRADUATE PROGRAM DIRECTORATE

We hereby certify that we have read and evaluated this Thesis entitled ‘‘**Effect of Rhizobium Inoculation and NPSB Fertilizer Rates on Growth, Yield and Yield Components of Mung bean (*Vigna radiate* (L.) Wilczek) Varieties in Misirak Meskan District, Eastern Gurage Zone.**’’ prepared under our guidance by **Mohammed Wulchafo**. We recommend that it be submitted as fulfilling the Thesis requirement.

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As members of the Board of Examiners of the MSc Thesis Open Defense Examination, We certify that we have read and evaluated the Thesis prepared by Mohammed Wulchafo and examined the candidate. We recommend that the Thesis be accepted as fulfilling the Thesis requirement for the degree of Master of Science in Plant Science Agronomy.

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Final approval and acceptance of the Thesis are contingent upon the submission of its final copy to the Council of Graduate Studies (CGS) through the Graduate Committee (SGC) of the candidate’s School.

DEDICATION

I dedicate this thesis to my lovely wife and my family for their concern, prayer, patience, encouragement, and love in the success of my life.

STATEMENT OF AUTHOR

First, I declared that this thesis is a result of my genuine work and that I have duly acknowledged all sources of materials used for writing. I submitted this thesis to Wolkite University in partial fulfillment for the Degree of Master of Science in Agronomy and it is deposited in the library of the University to be made available to borrowers for reference. I solemnly declared that I have not so far submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author, Mohammed Wulchafo Badkaro was born on October 12, 1986 at Butajira town, Gurage Zone, Southern National Regional State. He attended his Primary School at Koto and his Secondary and Preparatory Schools at Butajira. He joined Haramaya University, College of Agriculture and Natural Resource Management in 2010 G.C and graduated with BSc Degree in Rural Development and Agricultural Extension in 2013 G.C.

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ABBREVIATIONS AND ACRONYMY

AE	Agronomic Efficiency
ANOVA	Analysis of Variance
ATA	Agricultural Transformation Agency
BBS	Bangladesh Bureau of Statistics
BNF	Biological Nitrogen Fixation
CEC	Cat ion Exchange Capacity
CSA	Central Statistical Agency
ECX	Ethiopian Commodity Exchange
EEPA	Ethiopian Export Promotion Agency
FTC	Farmers Training Center
FAO	Food and Agricultural Organization
IFPRI	International Food Policy Research Institute
MARC	Melkasa Agricultural Research Center
MOARD	Ministry of Agriculture and Rural Development
SADAFF	South African Department of Agriculture, Forestry and Fisheries

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

LIST OF APPENDIXES

Effect of Rhizobium Inoculation and NPSB Fertilizer Rates on Growth, Yield and Yield Components of Mung bean (*Vigna radiate* (L.) Wilczek) Varieties at Misirak Meskan District, Eastern Gurage Zone

ABSTRACT

Lack of adequate information on the use of Rhizobium strain and nitrogen-phosphorus-sulfur-boron (NPSB) fertilizer rates are the major yield limiting factors for producing mung bean in the study area. Therefore, the study was conducted with the objective of evaluating the nodulation, growth and yield responses of two varieties of mung bean (Vigna radiate (L.) Wilczek) at different rates of NPSB fertilizer and Rhizobium inoculates. A field experiment was carried out during the main cropping season of 2021/22 at Misirak Meskan District in Farmers Training Center (FTC). The treatments combinations were two levels of Rhizobium inoculation (with and without), two mung bean varieties N-26 (Rassa) and NVL-1(Nassa) and four levels of NPSB fertilizer (0, 50, 100, 150 kg ha^{-1}). The experiment was arranged in a 2×2×4 factorial combination in randomized complete block design with three replications. Soil samples were collected from the experimental field at (0-30cm depth) before planting and after harvest to determine selected soil physicochemical properties. Data on growth, nodulation, yield and yield components were recorded and subjected to Analysis of Variance (ANOVA). Results on soil physicochemical properties analyzed before planting and after harvest showed significant differences due to the combined effects of NPSB fertilizers and Rhizobium inoculation. Crop phenology (days to 50% flowering and days to physiological maturity), growth (plant height, number of primary and secondary branches, shoot fresh and dry weight, root dry weight), and nodulation (number of nodules, nodule fresh and dry) weight of mung bean varieties were significantly affected by NPSB fertilizer rates and Rhizobium inoculation. Moreover, the interaction effects of NPSB fertilizer rates, Rhizobium inoculation and mung bean varieties showed significant effects on number of pods per plant, number of seeds per pod, a hundred seed weight, harvest index, grain yield and above ground biomass. The highest mean value of grain yield(2105.77 kg ha^{-1}) was obtained from a combined effect of 150 kg NPSB ha^{-1} and Rhizobium inoculation from variety N-26 which resulted in 61.28% followed by (2078.90 kg ha^{-1}) which was increased by 62.07% at the rate of 100 kg NPSB ha^{-1} increase over the control (1290.37 kg ha^{-1}). Furthermore, the number of seeds per plant, a hundred seeds weight, above ground dry biomass and HI of mung bean were recorded the highest mean values (607.33), (7.50 g), (4241.67 kg ha^{-1}) and 0.483, respectively at the rate of 150 kg NPSB ha^{-1} fertilizer with a Rhizobium inoculation. The partial budget analysis revealed that the maximum (ETB 108600.6 ha^{-1}) net benefit was obtained from combined application of rhizobium inoculation and 100 kg NPSB ha^{-1}from variety N-26 with MRR of 10130%

And minimum (ETB 68572.8 ha^{-1}) net benefit was obtained from the control. A net benefit advantage of 63.14% (ETB 68572.8 ha^{-1}) when compared with the maximum and minimum net benefit. Hence, Rhizobium inoculation with application of 100 kg NPSB ha^{-1} could be tentatively recommended for mung bean production in Misirak Meskan area. However, the experiment should be repeated over years and locations to provide valid recommendations appropriate for the study site.

Keywords:, *Mung bean, NPSB fertilizers, Rhizobium inoculation, Yield, Economic analysis*

1. INTRODUCTION

Mung bean (*Vigna radiata* L.Wilczek) is a major crop grown in tropical and subtropical regions of the world and is also known as green gramme (bean) (Khan *et al*., 2012; Kumari *et al*., 2012). It is an ancient and well-known pulse crop of the Papilionoideae family that originated in India and has spread throughout South East Asia (Mogotsi, 2006). The crop characteristics include rapid growth in hot weather, low water requirements, and significant soil fertility enhancement through nitrogen fixation (Yagoob, 2014). Mung bean has unique characteristics such as its early maturity, high yield, drought-resilience, and ability to stimulate striga without being parasitized (Georgis, 2010).

The crop has a high nutritional value and a low cost for consumers (Asrate *et al*., 2012; Wedajo, 2015). It is eaten in a variety of forms, including seeds, sprouts, and immature pods, which are all high in amino acids, vitamins, and minerals (Somata *et al*., 2007). The protein, fat, and carbohydrate contents of the grain are 24.2, 1.3, and 60.4 percent, respectively (Hussien *et al*., 2012). The production status of Mung bean is dominant by China mainland (83.5; 50.6%), Indonesia (4.2; 9.0%), India (3.1; 3.0%), Turkiye (2.4; 2.3%), France (1.7; 12.6%), Thailand (1.3; 2.0%), Egypt (1.2; 0.7%) and Morocco (1.1; 1.4%); hence this eight top bean producer country is covered 99 % of world production and 83 % of area harvested (FAOSTAT, 2021).

In Ethiopia, Mung bean “Masho” is produced both for local consumption and export market. For instance, in 2021/22 cropping season the total area under production was 56,015.7 hectares with the production of 55,371 tons production in Ethiopia (MoA, 2022). The demand for Ethiopian Mung bean export has grown slightly from 822,000 kg in 2001 to 26,743,000 kg in 2014 to fulfill the demand of India, Indonesia, Belgium, and the United Arab Emerit (UAE) (MoARD, 2015). For illustration, in 2022/2023, Ethiopia exported a total of 30,694 metric tons of green Mung bean with a value of 35.8 million USD. In the comparison of export performance in 2021/2022, the export volume and value grew up by 21% and 23%, respectively (ECX, 2014). The major Mung bean producer regions in the country includes Amhara region, accounting for 66.3% production in a million tons and 69.7% area harvested followed by Oromia 30.3% and

28.0%, Southern Nation and Nationalities People 2.1% and 2.1%; and Afar 1.3% and 0.2% of the total area in hectare and production in tons respectively (CSA, 2021).

The trend of Mung bean production in a million tons and area harvested in Ethiopia is almost declining. For instance, the Mung bean production area in hectare and ton in 2020 was estimated to be 47175 ha and 50665.2 ton, respectively; whereas 56016 hectares and 57158.8 ton in 2021(CSA, 2021). Therefore, the production, area coverage and yield are declining due to limited availability of improved and high yielding variety, poor management option, lack of seed system and poor extension attention, soil fertility problem that could be due to lack of appropriate recommended inorganic and organic fertilizers like Rhizobium inoculations.

Though, Mung bean is usually managed with low fertilizer input, and has shown variable growth pattern and yield response Mulu *et al.* (2022); it seems that there is little investigation on combined effects of NPSB fertilization and Rhizobium inoculation on growth attributes and yield of Mung bean. For instance, Muhammad *et al*. (2016) who represented the best suitable rhizobial strain should meet the following criteria it should have an ability to colonize in the soil and tolerate environmental stresses, ability to form effective nodules, to compete with population of background Rhizobia for nodule formation. Moreover, Romdhane *et al.* (2009) stated greater number of nodules in inoculated treatments compared with non-inoculated ones that relied on indigenous Rhizobia this is due to the inoculated bacteria strain having a higher nodulation inducing capacity than the native soil Rhizobium population (Habtamu *et al*., 2017).

Previous research by Tena *et al.* (2016) also indicated that significantly increased a hundred seed weight and seed yield ha^{-1} of mung bean from inoculation with Rhazobium Bradyrhibium. On the other hand, although Rhazobium strains is not widely used by farmers in Ethiopia, though rhizobium strains were chosen and distributed to farmers to aid in the fixation of the target legumes crop varieties (Habtamu *et al.*, 2017). Anteneh (2016) also described that the highest grain yield of 3286.27 and 2951.36 kg ha^{-1} at Haramaya and Hirna, respectively with inoculation of common bean with rhizobium strain.

In Misirak Meskan district, site-specific blended fertilizer recommendation was carried out by Agricultural Transformation Agency (ATA) for most of crops grown in the area. However, there were limited investigations made in the study area on the application of blended (NPSB) fertilizers rates for different Mung bean crop varieties. In addition, so far there was limited number of researches has been carried out on the effect of NPSB blended fertilizer and Rhizobium inoculation on improved mung bean varieties in the study area. Therefore, the above-mentioned concerns initiated this research to be conducted to investigate the effects of blended NPSB fertilizer rates and Rhizobium inoculants on yield and yield components of Mung bean (*Vigna radiata* (L.) Wilczek) varieties in Misirak Meskan district, Eastern Gurage. In view of this, the study was conducted with the following general and specific objectives.

1.1. General objective

- To investigate the effects of blended NPSB fertilizer rates and Rhizobium inoculants on nodulation, growth, yield and yield components of Mung bean (*Vigna radiata* (L.) Wilczek) varieties in Misirak Meskan district, Eastern Gurage.

1.2. Specific Objectives

- To evaluate effects of NPSB fertilizer and Rhizobium inoculation on nodulation, growth, yield and yield components of Mung bean in the study area.
- To determine the interaction effect of blended NPSB fertilizer and Rhizobium on nodulation, growth, yield and yield component of Mung bean varieties.
- To determine the economic feasibility of blended NPSB fertilizers rates and Rhizobium inoculation for mung bean production in Misirak Meskan district.

2. LITERATURE REVIEW

2.1. Origin, Distribution and Botany of Mung bean

Mung beans originated in India or the Indo-Burmese region, where they have been cultivated for many years. It quickly spread to most other Asian countries, and more recently, to other continents. It is a high yielding pulse crop that is widely grown in Southeast Asia, Africa, South America, and Australia (SADAFF, 2010). Mung bean cultivation has spread all over the world due to the short time it takes to grow, its wide adaptability, and the ease with which it can be digested (Chadha, 2010). Botanical characteristics of the crop is an annual crop which is 0.3 to 1.5 m tall, erect or sub-erect plant, sometimes slightly twining at the tips. It is deep rooted, much branched with long petioles. The leaves are alternate, trifoliate and dark or light green, the leaflets ovate and vary from 5 to 12 cm wide and 2 to 10 cm long. The inflorescence is an auxiliary raceme with a peduncle 2 to 13 cm long. The flower is yellow and the keel petal is spirally coiled with a horn-like appendage (Sehrawat *et al*., 2013). Pods are 6 to 10 cm long, slender, short and hairy. Seeds are globose, weight 15 to 85 mg, mostly green but sometimes yellow, tawny brown, black or mottled and germination is epigeal (Bailey, 1970).

2.2. Agro-ecological Requirements of Mung bean

The extensive allocations of mung bean are tropics and subtropics. It is a short-day plant. Cultivars vary markedly in sensitivity, but most genotypes illustrate quantitative short-day responses, flower initiation being delayed by increases in the length of the photoperiod. Qualitative responses (no flower initiation if photoperiod longer than a certain critical value) occur, while absolute day neutrality has yet to be confirmed (Siemonsma and Arwooth, 2016). Seed can be planted when the minimum temperature is above 15°C. Adequate rainfall is required from flowering to late pod fill for purposes of ensuring good yield. It does best on fertile, sandy loam soils with good internal drainage and a pH in the range of 6.3 and 7.2 and it does not tolerate saline soils and can show severe iron chlorosis symptoms and certain micronutrient deficiencies on more alkaline soils (SADAFF, 2010)

2.3. Importance of Mung bean

Mung bean is grown for human consumption as well as fodder (Lee *et al.*, 1997). Plant parts are used as fodder and green manure, and seeds, sprouts, and young pods are consumed as sources of protein, amino acids, vitamins, and minerals (Prakit and Peerasak, 2007). Because its seeds are high in protein and amino acids, it has the potential to fill the gap in protein supply for humans. In diets, it can provide significant amounts of protein, carbohydrate, and a variety of micronutrients (Anwar *et al.*, 2007). It is also one of the most important income-generating grain legumes (Chadha, 2010; SADAFF, 2010). Mung bean demand is increasing in the global import-export market (Zhichao *et al.*, 2018). It is added to the list of commodities exported from Ethiopia by ECX (ECX, 2014).

2.4. Production of Mung bean in Ethiopia

Mung bean is grown in lower, drier and warmer areas of Ethiopia (Itefa, 2016). It has been produced in different areas like Shewa, Hararge, Ilubabor, Gamogofa, Tigray and Gondar (Keatinge *et al.*, 2011). Its cultivation is gaining popularity from time to time among the farmers and Ethiopia's mung bean export has grown slightly from year to year. Though its production in Ethiopia is very negligible when it is compared to other pulse crops, small holder farmers in drier marginal environments grow mung bean and it has been an important grain legume for resource poor farmers in these areas (Itefa, 2016; MOARD, 2008). Asrat *et al*. (2012) reports showed that the production of mung bean is very low in Ethiopia as compared to other state of the world especially in relation to soil fertility apparently due to limited correction through application of fertilizers.

2.5. Effect of N, P, S and B on Growth and Yield of Mung bean

2.5.1. Nitrogen (N)

Nitrogen is an important mineral whose nutritional management requires special attention due to its diverse roles in plant physiology and metabolites biosynthesis, as well as its dynamics in soil Noroozlo AY and Mohammadipour N.,2019). According to Malik Mahmood (2003) and Nuru (2020) results mung bean increase in plant height with the increased NPS application rate indicates maximum vegetative growth of the plants under higher N and S availability and P also, plays a pivotal role in early root proliferation that might increase the nutrient up take of the plant. On the other hand, an adequate P availability improves the nodule number and N content in the tissues of mung bean (Bashir *et al*., 2011). Mung bean require more N in the reproductive stage than in the vegetative stage and essential for crops as source of proteins and play beneficial roles on crop performance which contribute for maximizing production (Davis and Brick, 2009). High level of P in the soil helps the uptake of other nutrients, which ultimately produces healthy plant with the maximum productive branches of the crop (Hamza *et al*., 2016, Razaq *et al*., 2017). Furthermore, Sadeghipour *et al.* (2010) concluded that application of N and P fertilizers, increased number of pods per plant, number seeds pod, 1000 seeds weight and seed yield. In addition, sulfur involves in metabolic and enzymatic processes including photosynthesis, respiration and legume-rhizobium symbiotic N fixation (Rao *et al*., 2001). For instance, without N it is not possible to synthesize the necessary proteins, enzymes, DNA and RNA required in virtually all plant cells for their initial development, sustained growth and functioning to support other tissues of the plant (Mozumder *et al*., 2003). The nitrogen deficiency is frequently a major limiting factor for high yielding crops all over the world (Namvar *et al.*, 2011). According to Tario *et al*. (2013) reported that the increase of plant height with the increment of the rates of NPS fertilizer might be due to the fact that nitrogen, phosphorus and sulfur nutrients are involved in vital plant functions and contribute to enhanced growth in the height of the crop. In addition, N is also found in chlorophyll that enables the plant to transfer energy from sun light by photosynthesis. It influences cell size, leaf area and photosynthetic activity (Kibe *et al*., 2006; Caliskan *et al*., 2008; Salvagiotti *et al.*, 2008). In overall, N deficiency causes a reduction in growth rate, general chlorosis, often accompanied by early senescence of older leaves, and reduced yield (Caliskan *et al*., 2008; Erman *et al*., 2011).

2.5.2. Phosphorus (P)

On the other hand, Jan *et al*. (2012) reported that the application of phosphorus might have improved the nutritional environment in Rhizosphere. It favors in plant system to increased uptake and translocation of nutrients in reproductive structures and enhance root growth, improving flower formation and seed production (Havlin *et al*., 2004). For instance, the application of phosphorus to mung bean has been reported to increase dry matter at harvest, number of pods plant^{-1}, seeds pod^{-1}, 1000 grain weight, seed yield and total biomass (Naeem *et al*., 2000). Such positive effects of a high P supply on nodule development are associated with the essential function of P in energy metabolism (Tang *et al*., 2001). Moreover, phosphorus application along with other micronutrients can increase the biological activities, which result in improvements to plant height, number of nodules plant^{-1}, number of pods plant^{-1} and enhanced straw quality (Kumar *et al.,* 2012). Similarly, Khan *et al.* (2002) obtained a linear increased trend in total biomass, straw yield and grain yield of mung bean with increasing the rates of phosphorous fertilizer. Adequate P availability improves the nodule number and N content in the tissues of mungbean (Bashir *et al*., 2011).

2.5.3. Sulfur (S)

Fertilizers also have key roles in pod filling and ultimately enhance the grain production (Xavier and Germida 2002). The application of sulfur increases the concentration as well as total uptake of N, P,K, Ca, S, Zn and B at different stages of crop growth (Agrawal *et al*., 2000). As sulfur promotes the formation of legume nodules and stimulates the production of seeds. Application of S up to 20 kg ha^{-1}, the total number of nodules and active nodules increased significantly (Ganeshamurthy and Reddy, 2000). A significant increase in the number of active nodules with the application of sulfur up to 20 kg ha^{-1} because sulfur is involved in the formation of nitrogenous enzyme known to promote nitrogen fixation in legumes (Scherer *et al*., 2006).

Singh, (2001), it improved flowering, analysis, pod formation, higher numbers of seeds pod^{-1}, yield and quality. Different researchers similarly reported a significant result of NPS application on yield and yield attributing traits of legumes (Dame and Tasisa, 2019; Deresa *et al*., 2018). Eriksen *et al.* (2004) also stated that less S is being added to soils as a result of the reduced use of

S-containing fungicides and pesticides, as well as the reduction of sulfur dioxide emissions from industrial sources.

2.5.4. Boron (B)

Mung bean receives boron maintained a higher light interception ratio, leaf area index, biomass production, crop growth rate and net assimilation ratio, which resulted in higher harvest index and seed yield (Renukadevi *et al*., 2002). Therefore, boron availability at an early stage enhances leaf chlorophyll content, leaf stomata conductance, net photosynthetic rate and non-structural carbohydrate export from leaf to the yield-attributing sink (Bhattacharya *et al*., 2004; Osterhuis and Zhao, 2006). The boron improves the grain and straw yield, phosphorus content, nutrient uptake and quality in legume crops (Singh *et al*., 2006). Boron increases the leaf area expansion, 1000 seed weight, nodule formation, seed yield and biological yield as well as the growth and yield and growth of plants. Sulfur and boron has a great importance on yield and yield components of mung bean (Halwai *et al*., 2016).

Ali and Mishra (2001), who noted that boron favored better root growth and nitrogen assimilation with higher nodulation, which in consequence resulted in better growth and development of sink size and ultimately higher yield. Thus, the number of seeds, number of pods and seed yield increased with residual boron availability (Verma *et al*., 2004). The different levels of sulfur and boron significantly varied the plant height, total pods plant^{-1}, pod length, grains pod per plant, 1000 seed weight and yield (Renukadevi *et al*., 2002). According to Verma *et al*. (2004) its impact the pollen producing capacity, pollen tube growth, anther viability of pollen, grain and pollen germination. For instance, the application of B because pectin is internalized by cross-linking with boron which increases the number of seeds pod per plant in mung bean.

2.6. Rhizobium inoculants and its Role

Rhizobium inoculants coated on seeds of pulse crops before planting not only enhance growth and yield of the pulse crops but also provide nitrogen and organic carbon for subsequent or associated crops; and incorporating residues of pulse crops back into the soil will make this effect even more significant (Gan *et al*., 2015).The use of biological nitrogen fixation (BNF) technology in the form of Rhizobium inoculants in grain legumes can be an alternative of nitrogenous fertilizer (Aziz *et al*., 2016).

Bio-fertilizers are valued to the environment as they enable reduced use of chemical fertilizers since they contain naturally occurring micro-organisms that are biologically multiplied to improve soil fertility and crop productivity in many parts of the world (IFPRI, 2010). They are also relatively low-cost source of nitrogen for smallholder farmers in Ethiopia (Gorfu *et al*., 2000) Bio-fertilizers play an important role in increasing availability of nitrogen and phosphorus besides increase in biological fixation of atmospheric nitrogen and enhance phosphorus availability to crop. Therefore, introduction of efficient strain of Rhizobium in soil enhances the quality of soil by providing more nitrogen fixation and which may be helpful in boosting up production. The plant rhizosphere is a major soil ecological environment for plant microbe interactions involving colonization of different microorganisms in and around the roots of the growing plant. This colonization may either result in associative, symbiotic, neutralist or parasitic interaction, depending upon the plant nutrient status in the soil environment (Rannie and Larson, 1979). Rhizobia species are usually defined as nitrogen-fixing soil bacteria capable of inducing the formation of root or stem nodules on leguminous plants in which atmospheric nitrogen is reduced to ammonia for benefit of the plant (Boivin *et al*., 1997). The inoculation of seeds with Rhizobium increase nodulation, N uptake and seed protein (Bejandi *et al*., 2011). To insure optimum Rhizobium populations in the rhizosphere, seed inoculation of legumes with an efficient Rhizobium strain is necessary. Seed and soil inoculation alone and in combination with lower dose of N fertilizer (15-30 kg^{-1}) increased root growth, nodulation, plant growth, pod and seed development and seed yield of mung bean (Ahmed *et al*., 2006). The use of appropriate strains of inoculants in N deficient soils may offer an excellent opportunity for improving legume growth and development (Mfilinge *et al*., 2014). Delic *et al*. (2019) conveyed that all investigated characteristics of grain and shoot dry matter yields of mung bean significantly increased due to seed inoculation with particular Rhizoidal strains.

2.7. Role of Rhizobium inoculation on Growth and yield of Mung bean

The term Rhizobium inoculation refers to the use of various live microorganisms that enhance soil fertility by fixing atmospheric nitrogen, solubilizing or mineralizing phosphorus and potassium or decomposing organic wastes or by producing plant growth-promoting substances at the root zone (Mohammadi and Sohrabi, 2012). Bio fertilizers, as one of the important components of sustainable agriculture, are products holding living microorganisms which have the capacity to mobilize nutritionally important elements from non-usable to usable form through biological processes and they have the potential to increase the production of crop by improving yield and quantity (Glazer and Nikado, 2007). So, there is an ample scope of increasing the yield of mung bean by using proper fertilization combined with rhizobium inoculation(Santos *et al*., 2004). Seed inoculation significantly increased the growth parameters of mung bean (Khan and Kounsar, 2000). Symbiotic relationships of the rhizobia also play a key role in improving the quality and productivity of the soil. When seed inoculation with Rhizobium, colonize plant roots, increase plant growth, development, nodulation and yield of legume crops by multifarious mechanisms, such as control of soil borne and systemic pathogens, beneficial activities in terms of nutrients availability and production of enzymes and plant growth regulators (Arora *et al.*, 2001).The inoculation of seeds with Rhizobium increase nodulation, N uptake and seed protein (Bejandi *et al.*, 2011).

Rhizobial bio-fertilizers are selected strains of beneficial soil microorganisms cultured in laboratory and packed in a carrier or without carrier. Despite these fertilizers improve nutrient availability, enhance pest tolerance and stimulate plant growth, nitrogen fertilization of the rhizosphere remains to most prevalent rhizoidal bio-fertilizers help enhance production and productivity of grain legume crops. It also improves protein quality of grain legume crops. Inoculation of mung bean with Rhizobium increased the grain yield, photosynthetic activity and dry matter production (Muhammad *et al*., 2016). According to Malik *et al*. (2002) reported that seed inoculation with Rhizobium significantly increased 100-seed weight of mung bean.

2.8. Yield and Yield Components Response of Mung bean to Combined Effect of N, P, S and B Fertilizers with Rhizobium Strains

Soil micro-organisms play a significant role in regulating the dynamics of organic matter decomposition and the availability of plant nutrients such as N, P and S (Place *et al*., 2003). Among significant factors inoculants strains and fertilizers are the key contributors for mung bean production it showed that seed yield per plant of mung bean showed positive correlation with number of nodule per plant, number of pod per plant, number of seed per pod and 100-seed weight of mung bean (Delic *et al*., 2019; Rahman *et al*., 2008). The highest result from NPSZn*MB003 might be especially due to the influence of S for cell division, enlargement and elongation, and the growth enzymes activation of Zn (Ayalew Kebede, 2019).

According to Rahman *et al*. (2008) significant effect was observed on 100-seed weight due to the application of phosphorus, molybdenum and Rhizobium inoculation. The increase in 100 grain weight showed that micronutrients along with Rhizobium inoculation (MB003) are necessary for healthier and robust seeds in mung bean (Ahmad *et al*., 2013). Legumes depend on symbiotic nitrogen and receive an inadequate supply of phosphorus, they may suffer from nitrogen deficiency (Weisany *et al*., 2013) as a result of poor N_2 fixation. The combination of Rhizobium inoculum and three chemical fertilizers (N, P and K) showed significant effects on 1000-seed weight of mung bean (Hossain *et al.*, 2011). Rhizobium inoculation strains combined with NP fertilizers increased pod number per plant of mung bean (Ashraf *et al*., 2003). The founding of Muhammad *et al*.(2016) who reported that the higher grain yield from interaction of N, P and Rhizobium strains is attributed to higher number of pods per plant, number of grains per pod and 1000 seed weight.

2.9. Nutrient Response of Mung bean for the Interaction of N, P, S and B Fertilizers with Rhizobium Strains

In symbiosis with legumes, Rhizobium bacteria have the ability to fix N from the air (N_2). Thus, the huge natural source of N from the air can be taken up from the symbiotic association which leads to decrease or absence of N mineral fertilizer application in the field (Abbas *et al.*, 2011; Rahman *et al.*, 2002). The highest (90.48 kg/ha) N uptake of mung bean was recorded from interaction of NPSB blend fertilizer with Rhizobium strain, whereas the lowest (43.04 kg/ha) was obtained from the control unit (Ayalew, 2019). The deficiencies limit N fixation by the legume-Rhizobium symbiosis and decrease yield of legumes, nutrient limitations in legume production result from deficiencies of not only macro nutrients but also micronutrients this deficiency can be overcome by applying Rhizobium strains and providing essential nutrients in the soil (Fatima *et al.*, 2007).

The Rhizobium strain bacteria enhance the availability of P to the plants, which might have led to greater root development and nodulation which in turn resulted in higher N fixation in the soil by nodules (Ayalew, 2019). Soil micro-organisms play a significant role in regulating the dynamics of organic matter decomposition and the availability of plant nutrients such as N, P and S (Place *et al.*, 2003). In case of economic importance, high economic outputs of mung bean especially in the developing countries were reflected in many ways. Such as it has an ability to be cultivated in arid areas, can be grow on marginal lands as well as able to improve soil quality due to ability of symbiotic nitrogen fixation (Delic *et al.*, 2011).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study was conducted in the Farmer's Training Center (FTC) demonstration site in Misirak Meskan district, Eastern Gurage zone, in Central Ethiopia, in 2021 during main cropping season. Misirak Meskan district is geographically located at 151km South of Addis Ababa at elevation of 1702 meter above sea level (Figure 1). The rainfall distribution is bimodal, where the short rainy season is from March to May and the long rainy season is from June to September (Figure 2). The experimental site receives an annual average rain fall of 701-1200 mm, and an average temperature ranges between 10.28 to 24.04 ^{0}C (Figure 2) with a clay loam soil.

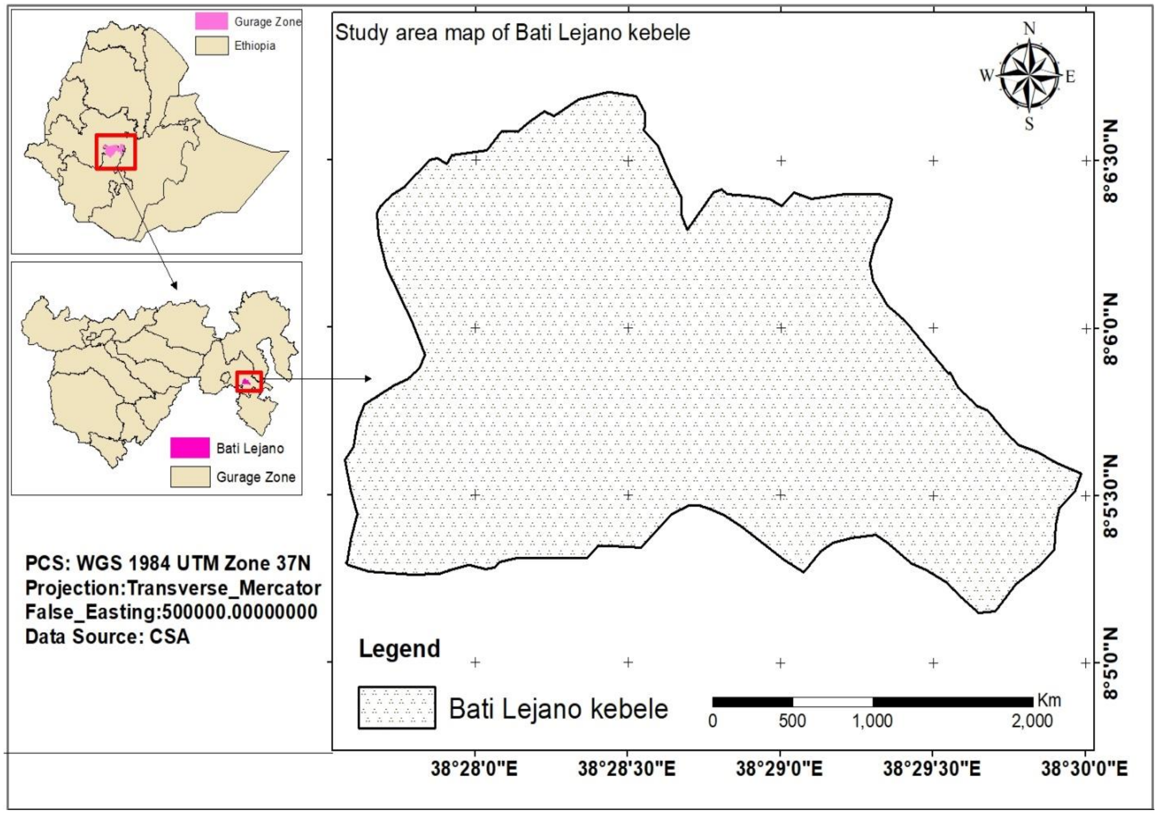

Figure 1. Location Map of the study area (Misrak Meskan woreda)

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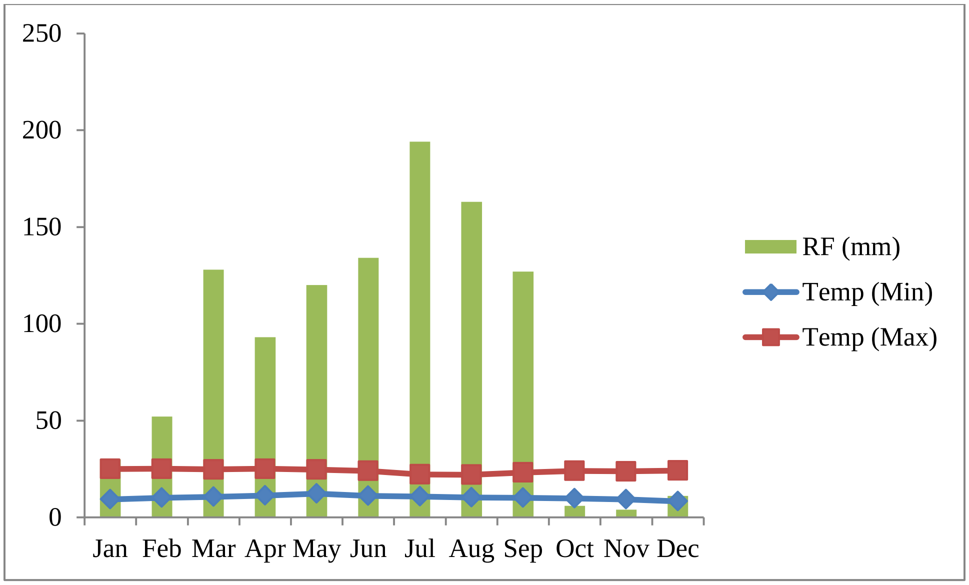

Figure 2.Mean monthly rainfall (RF), minimum (Temp Min) and maximum (Temp Max) temperatures

3.2 Experimental Materials

3.2.1. Mung bean varieties

The experiment was conducted using the improved mung bean varieties Rasa (N-26) and NVL-1 that were released by Melkassa Agricultural Research Center in 2011 and 2014 years (Table 1).

Table 1. Improved varieties of mung bean and some agronomic characteristics

No	Genotypes	Year of release	Seed size	Status	Altitude	Rainfall	Yield (t/ha)		Source
							Far	Res	
1	Rasa(N-26)	2011	small	Released	1000-1650	750-1000	1.4	1.8	MARC
2	NVL-1	2014	small	Released	1000-1650	750-1000	1.4	1.8	MARC

Source: wondimkun ,Dikr,(2023) , Far= Farmers site, Res = research site.

3.2.2. NPSB fertilizer

Blended NPSB fertilizer (N = 18.9 kg, P_2O_5 = 37.7 kg, S = 6.95 kg, B = 0.1 kg) was obtained from agricultural office of Misirak Meskan district.

3.2.3. Inoculants

The rhizobium inoculants (MB003) for seed treatment purpose were obtained from Menagesha Biotechnology Industry P.L.C., Ethiopia.

3.3. Treatments and Experimental Design

In this study, a factorial combination of two mung bean varieties (N-26 and NVL-1), four NPSB fertilizer rates (0, 50, 100 and 150kg/ha) and two Rhizobium inoculation treatment (R0, = un inoculated and R1= inoculated) were laid out in Randomized Complete Block Design (RCBD) with three replications. The experiment had a total of sixteen (2*4*2 =16) treatment combinations (Table 2). Treatments were assigned randomly to the experimental plots within the block. Each block had sixteen experimental plots corresponds to the sixteen treatments. The experiment had a total of 48 experiment plots. The size of each experimental plot was 6.4 m^2 (3.2 m * 2 m) that accommodated 8 rows and 20 mung bean plants per row spaced at 40 cm between rows, 10 cm between plants with a net plot area of 3.60 m^2 (2 m * 1.8 m) with a total number of plants in the gross and net plot area were160 and 90 mung bean plants, respectively. The spacing between each plot and block was 0.5 m and 1 m, respectively. The blanket recommendation of NPSB fertilizer is 100 kg/ha (18.9N, 37.7P_2O_5, 6.95 S and 0.1B) (ATA, 2016). All the agronomic practices were uniformly performed to all plots as per recommendations for the area (Dikr, 2023).

Table 2. Treatment combinations of the experiment

Treatments	Rhizobium Inoculants	Variety	NPSB Fertilizer level kg/ha
T1	R0	Rasa (N-26)	0
T2			50
T3			100
T4			150
T5		NVL-1	0
T6			50
T7			100
T8			150
T9	R1	Rasa (N-26)	0
T10			50
T11			100
T12			150
T13		NVL-1	0
T14			50
T15			100
T16			150

R0= Non inoculation, R1= Inoculation

3.4. Experimental Procedure and Trial Management

The experimental field was plowed two times by oxen to a depth of 30 cm to get a fine seed-bed and level manually before the field layout was made. Field layout was made, and each treatment was assigned randomly to the experimental units in three replications. Sowing was done on August 2021 by putting two seeds per hole 10 cm interval. From each experimental plot, plants were thinned manually by hand to one plant after emergence. The total amounts of blended fertilizer required for the research experimental plot was calculated based on each NPSB treatment rate. The fertilizer was applied manually at sowing time as per the treatments. The seed rate used for each variety was at a rate of 80 kg ha^{-1}.

The rhizobium, Bradyrhizobium strain species (MB003) was selected based on its ability to enhance modulation and grain yield under wide ecological condition for the varieties under consideration and also most of the mung bean producers have been used. Source of commercial Rhizobium strains were obtained from Menagesha Biotechnology Industry P.L.C that was purchased from the sole commercial inoculant producer in Ethiopia. The inoculants used for this study where lignite is carrier material and one mung bean Bradyrhizobium strains species (MB003).

Seeds were inoculated at a rate of 10g of inoculant per kg of seed (Mott, 2022). The 12.288g inoculants were needed at a rate of 10g of inoculant per kg of seed. The sticker material (sugar solution) was prepared by mixing 10 g of sugar with 100 ml of water. The seed was evenly coated with the sticker. One packet of to inoculate (125 g) was mixed with 200 ml of water to make a slurry. The seed required for the plot was mixed in slurry to have a uniform coating of inoculate over the seeds, and the seed was dried under shade for about 30 minutes (to avoid direct sunlight). The shade dried seed was sown within 24 hr. One packet of the inoculated (125 g) was sufficient to treat 10 kg of seed as per the recommendation (Mott, 2022).

3.5. Soil Sampling and Analysis

Soil samples were collected from the entire experimental field before sowing to the depth of 0-30 cm using an auger following a W-shape pattern. The soil sample was composited to 1 kg from 15 subsamples and taken to laboratory for analysis of selected soil physicochemical properties. Soil samples were collected from the entire experimental field after harvesting the crop to the depth 0-30cm using an auger following a W-shape pattern from each plot. The soil sample were taken 0.5kg per plot (the total samples are 48 taken) and taken to laboratory for analysis of selected soil physicochemical properties after harvesting the crop.

Soil texture was analyzed by the Hydrometer Bouyoucos method (Bouyoucos, 1962). Soil pH was measured using a digital pH meter in a 1:2.5 soil to water ratio (Rowell, 1994). Soil OC was determined by the Walkley and Black (1934) following a wet oxidation method. Total N of the soil was determined by the Kjeldahl method (Jackson, 1967). Available P was determined using Olsen extraction method (Olsen *et al*., 1954). Available S was determined using turbid metric method that by treating 20 g of 2 mm sieved soil with 25 ml 0.01 M of $CaCl_2.2H_2O$ extract and filtered. Available B was determined using hot water method (Havlin *et al.,* 1999). Cation exchange capacity (CEC) was determined following 1N neutral ammonium acetate (NH_4OAc) extract method (Van Reeuwijk, 1993).

3.6. Data Collection

The data were collected for all parameters including phenological, growth, nodulation, yield and yield components and described as below.

3.6.1 Phonological parameters

1. Days to 50% flowering: Days to flowering was recorded as number of days from emergence to the time when 50 percent of the plant population in each plot produce flowers (Jana grad *et al*., 2009).

2. Days to 90% maturity: Days to maturity were taken as the number of days after seedling emergence to the period when 90% of the plants in a plot ready for harvest as shown by change in the foliage and pod color and seed hardening in the pods.

3.6.2. Growth parameters

Plant height: Five plants were randomly taken from the four middle rows, and their height from the ground to the tip was measured using a ruler at physiological maturity and average value was taken.

Number of primary branches: Number of primary branches were determined by counting the number of primary branches from the main stem of five randomly selected plants from the net plot. Primary branches are the source of secondary branches and it attached to main stem.

Shoot fresh weight: Shoot fresh weight was measured using sensitive balance and the mean values from five plants were taken as shoot fresh weight per plant (g) under destructive (2^{nd}) row.

Shoot dry weight: The plants taken from under destructive row to measuring the shoot fresh weight then the plants were kept at 65^oC in oven until getting constant weight. The dry weight was measured using sensitive balance and the mean value from five plants were taken from (2^{nd}) row as shoot dry weight per plant (g).

Number of nodules: These were determined by counting the number of nodules from five plants per plot under destructive (2^{nd}) row and the mean value of the five plants were recorded as number of nodules per plant.

Nodules fresh weight: The collected nodules were labeled and placed in perforated paper bags, and the nodules fresh weight was measured.

Nodule dry weight: The nodule dry weight per plant was measured after drying the collected nodules in an oven with a temperature of 65 ^{o}C for 24-48 hrs until constant weight is attained. The dry weight was measured using sensitive balance and the average of five plants were taken as a nodule dry weight per plant (g) under destructive (2^{nd}) row.

Nodule volume: The collected nodules were immersed in previously measured volume of water in measuring cylinder. The volume of water displaced by nodules was considered as nodule volume (ml).

Number of effective nodules: Nodules were taken from five uprooted plants from each plot under destructive (2^{nd}) row and after dissecting with blade to observe their color in the center nodules with pink to brown color were considered as effective, and green and white color were sorted as non-effective nodules.

Root fresh weight: Shoot fresh weight was measured using sensitive balance and the mean values from five plants were taken as shoot fresh weight per plant (g) under destructive (2^{nd}) row.

Root dry weight: The five plants were taken under destructive (2^{nd}) row for determination of the dry weight of roots at flowering. After taking the fresh weight of root parts, the sample was dried in an oven at 65^{o}C to constant weight and then the dry weight was measured using sensitive balance and average of the plant root was taken (g).

3.6.3. Yield and yield components

Number of pods per plant: Number of pods per plant was recorded from five (to easily managed) randomly selected plants from the net plot area at harvest per plot. The average result was reported as number of pods per plant.

Number of seeds per pod: From five arbitrarily taken plants five pods were separated and threshed and then number of seeds was counted from five pods per plant and total number of pods to calculate average number of seeds per pod divided total number of seeds.

Above ground biomass (kg ha-1): At physiological maturity, plants from the net plot area at harvest were manually harvested close to surface. The ground the above-ground dry biomass of randomly ten plants was taken and it is measured after sun drying up to get constant weight. For obtaining the total aboveground dry biomass, the dried biomass per plant thus obtained is multiplied by the total number of plants per net plot and it is converted into kg ha-1.

Grain yield (Kg ha-1): It was determined by taking the weight of the grains after threshing from the net plot and adjusting the grain moisture content at 10% (100% - 10% = 90%) of the grain yield from the net plot area at harvest . Finally, the yield per plot was converted to kilogram per hectare (Hong and Ellis, 1996)

Hundred seed weight: This was recorded by weighing 100 randomly taken dry seeds harvested from the net plot using a sensitive balance and the weight was adjusted to 10% seed moisture content.

Harvest index %: Harvest index per plot was calculated as the ratio of dry seed yield per plot to the above ground dry biomass yield per plot.

$$\text{H.I.} = \frac{\text{Dry seed yield per plot(g)} \times 100}{\text{Above ground dry biomass yield per plot}}$$

3.7. Data Analysis

All collected data were subjected to ANOVA using SAS 9.3 version following the GLM procedure (SAS, 2011). Least Significance Difference LSD (5%) test was used to separate and compare among the means.

3.8. Economic Analysis

The economic analysis of NPSB fertilizer application and inoculant use on mung bean was evaluated using a partial budget analysis as described by CIMMYT (1988). Inorganic NPSB fertilizer and Rhizobium inoculant costs were considered as the variable costs. The variable costs of NPSB fertilizer ETB 3400 per 100 kg ha^{-1} and the price of purchased Rhizobium inoculant was

ETB 100 per 125g were taken from Menagesha Biotechnology Industry P.L.C. The price of the current mung bean grain at harvest was ETB 6000 per 100 kg taken from Office of Trade and Industry Marketing Case Team of Meskan District and local wage rate of ETB 80 per person per day.

The average yield was adjusted downward by 10% to reflect the farmer's field yield as described by CIMMYT (1988). A gross farm gate benefit was obtained by multiplying adjusted yield (kg ha-1) with farm gate price (ETB kg^{-1}); while the marginal rate of return for each treatment was calculated as a change of net benefit divided by change of variable cost and multiplied by 100 (CIMMYT, 1988).

4. RESULTS AND DISCUSSION

4.1. Soil Physicochemical Properties of the Study Area

4.1.1. Before planting

Selected soil physicochemical properties were analyzed for composite soil (0-30 cm depth) samples collected from the experimental site before planting. The results revealed that the particle size distribution in the soil was 38% clay, 32% silt and 32% sand with a textural class of clay loam (Table 3). The soil texture (proportion of clay, silt and sand in the soil) controls water contents, water intake rates, aeration, root penetration and soil fertility. The soil pH of 6.83 in the experimental site was rated as neutral (Tekalign, 1991). Mung bean grows on a wide range of soils but prefers well-drained loams or sandy loams, with pH ranging from 5.0 to 8.0 (Heuzé, 2015). Soil pH is an important parameter which measures hydrogen ion concentration in the soil to indicate its acidic and alkaline nature of the soil. Soil organic carbon is the carbon that remains in the soil after partial decomposition of any material produced by living organisms. It is present as a main component of soil organic matter and is believed to play a crucial role for many soil functions, ecological properties and nutrient provisioning, water-holding capacity and soil drainage, soil stability, and greenhouse gas emissions that can mitigate or accelerate climate change (Davidson and Janssens 2006, Jackson *et al*., 2017).

The soil organic carbon of the experimental site was of 2.31(Table 3) which is rated as high (Tekalign, 1991). The total nitrogen (TN) content of a soil can be classified as low (<0.05%), medium (0.05-0.12 %), high (0.12-0.25%) and very high (> 0.25%) (Tekalign, 1991). According to Tekalign (1991) ratings, the total N content of the soils (0.11%) in the study site was found to be medium (Appendix Table 4). Indicative ranges of available phosphorus have been established by Olsen *et al*. (1954), accordingly, the available phosphorus (14.69 pmm) content of the soil in the experimental site categorized as low (Appendix Table 5). Landon (2013) classification, the soils of the experimental site had CEC of 23.16 Cmol kg^{-1} which is considered as medium. The CEC value of the soil indicates that the soil has the capacity to hold nutrient cation and supply to the crop.

The extractable S content of the experimental site was 19.7 mg kg^{-1} (Table 3). According to Hariram and Dwivedi (1994) classification, the extractable S content of the soil of experimental site could be rated as medium, and it is indicative of soil capable of significant yield responses to the application of the appropriate level of the nutrient. Where extractable sulfur levels are less than 10 mg kg^{-1}, the deficiency is likely to occur for most crops. However, where levels are greater than about 20 mg kg^{-1}, toxicity may also occur (Hariram and Dwivedi, 1994).

Table 3. Selected physicochemical properties of the experimental soil before sowing

Soil Physical Properties	Results
Sand (%)	32
Clay (%)	38
Silt (%)	32
Textural Class	Clay loam
Soil Chemical Properties	
pH in water (1:2.5)	6.83
Total N (%)	0.11
Organic C (%)	2.31
Available P (pmm)	14.69
Extractable S (pmm)	19.7
Available B (mg kg^{-1})	1.18
CEC (cmol.(+) kg soil$_{-1}$)	23.16

CEC= Cation exchange capacity

The boron content of the experimental site was 1.18 mg kg^{-1} (Table 3). According to Jones (2003) classification, the boron content of the soil could be rated as medium, and it is indicative of soil capable of significant yield responses to the application of the appropriate level of the nutrient. Where soil B levels are less than 1.0 mg kg^{-1}, the deficiency is likely to occur for most crops. However, where levels are greater than about 5 mg kg^{-1}, toxicity may occur. In agricultural soils, B content varies from 0.5 to 5 mg kg^{-1} (Jones, 2003).

4.1.2. Effect of NPSB fertilizer rates and rhizobium inoculation on selected soil chemical properties after harvesting

4.1.2.1. Total nitrogen`

The analyzed soil data showed that rhizobium inoculation and the application of NPSB fertilizer rates increased the total nitrogen after harvest in soil (Table 4). However, the total N content of the sample from the control plot after harvest (0.157%) was somewhat increased as compared to the total N of the soil before planting (0.11%). Total Nitrogen ranged from 0.1533 from the control to 0.1760 (medium) under the application of 100kg ha^{-1} NPSB with inoculation at NVL-1 variety. Similarly, total nitrogen ranged from 0.1570 from the control to 0.1867 under the application of 0kg ha^{-1} to 100kg ha^{-1} NPSB with the variety N-26 under inoculated condition (Table 4). The maximum total nitrogen in the soil after harvesting was (0.187%) with the application of 100 kg NPSB ha^{-1} rate with rhizobium inoculation on variety (N-26). While the minimum total nitrogen after harvesting was (0.1533%) from 0 kg NPSB ha^{-1} rate (control) at the variety of (NVL-1) without rhizobium inoculation. The residual N in the soil was ranged from 0.1533 from 0 kg NPSB ha $^{-1}$ rate (control) at the variety of (NVL-1) without rhizobium inoculation to 0.187 (high) under the application of 100kg ha^{-1} rates of NPSB fertilizer with rhizobium inoculation on variety N-26 (Table 4). Therefore, the application of fertilizers NPSB with inoculation with N-26 variety increases total N content in the soil up to 21.98% over control treatment at the NVL-1 variety. Consequently, the application of fertilizers NPSB with inoculation increases total N content in the soil up to 13.5% over control treatment of the same variety.

4.1.2.2. Available phosphorus

Available P had 10.33 mg kg^{-1} achieved from the variety N-26 with the application rate of 0kg ha^{-1} NPSB without inoculation (Table 4). While, 21.62 and 21.63 mg kg^{-1} value had attained by from the application of 50 and 100 kg ha^{-1} on the variety N-26 with inoculation (Table 4). Hence, the application of 100 kg NPSB ha^{-1} with inoculation resulted in the highest available soil P content (21.63 mg kg^{-1}) which is a 103% increment as compared to that of the control plot (10.631 mg kg^{-1}). The available P content of the soil from the control plot after harvest was lower than the value obtained before planting, which may be due to the utilization of P by mung bean crop because of the crop used (Table 4). A similar result was also reported by Amsal and Tanner (2001) where higher rates of applied N decreased the level of residual soil P. The available P content of the soil from the control plot determined after harvest was lower than the value obtained before planting, which may be due to the utilization of more applied P by common bean crop (Atinafu, 2020). The residual P content in the soil was ranged from 19.93 to 21.63 mg kg $^{-1}$ at NPSB rate 150kg ha^{-1} to 100kg ha^{-1}. Ali et al. (2010) also reported significant effect of P fertilizer application rate on seed yield of mung bean.

Table 4. Effect of NPSB rates and Rhizobium Inoculation on Soil Chemical Properties after Harvest

Treatment	_NPSB Fertilizers							
	0		50		100		150	
Inoculants	R1	R0	R1	R0	R1	R0	R1	R0
Varieties								
	Total nitrogen (%)							
NVL-1	0.1627^{g}	0.1533^{i}	0.1657^{f}	0.1650^{fg}	0.1760^{bc}	0.174^{bcd}	0.1743^{bcd}	0.1737^{cd}
N-26	0.1647f^{g}	0.1570^{h}	0.1687^{e}	0.1593^{h}	0.1867^{a}	0.1767^{b}	0.1840^{a}	0.1760^{bc}
LSD (0.05)	0.0029							
CV (%)	1.036							
	Available phosphorus (mg kg $^{-1}$)							
NVL-1	11.96^{fg}	12.59^{e}	15.78^{d}	12.46^{ef}	17.09^{c}	12.55^{e}	16.81^{c}	11.91^{fg}
N-26	12.46^{ef}	10.63^{h}	21.62^{a}	11.86^{g}	21.63^{a}	16.21^{d}	19.93^{b}	11.92^{fg}
LSD (0.05)	0.56							
CV (%)	2.25							
	Extractable sulfur (mg kg $^{-1}$)							
NVL-1	12.69^{h}	11.88^{h}	16.02^{g}	18.06^{f}	21.12^{bcd}	20.59^{cd}	20.43^{de}	21.55^{bc}
N-26	17.89^{f}	17.31^{f}	20.41^{de}	19.53^{e}	22.78^{a}	21.71^{b}	22.14^{ab}	21.20^{bcd}
LSD (0.05)	1.07							
CV (%)	3.26							
	Available boron (mg kg $^{-1}$)							
NVL-1	51^{h}	0.36^{i}	1.11^{de}	0.60^{g}	1.39^{b}	1.04^{e}	1.38^{b}	1.22^{c}
N-26	0.60^{g}	0.41^{i}	1.14^{d}	0.70^{f}	1.51^{a}	1.40^{b}	1.49^{a}	1.30^{c}
LSD (0.05)	0.08							
CV (%)	4.82							

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation

4.1.2.3. Extractable sulfur

The sulfur content in the soil after harvesting was numerically indicated increasing trend with the increasing rates of applied sulfur in the blended fertilizer rates with rhizobium inoculation. The extractable sulfur content of soil under control plot was relatively higher than the plot received different blended fertilizer rates, except for the application of 100kg ha^{-1} NPSB fertilizer rates with rhizobium inoculation and 150 kg NPSB ha^{-1} (Table 4). The highest available sulfur (22.78 and 22.14 mg kg^{-1}) content of the soil after harvesting was obtained from plots treated with 100kg and 150 kg NPSB ha^{-1}, respectively. The extractable S content of the soil from the experimental field determined after harvest was higher than before planting, which might be due to less sulfur nutrient uptake by the mung bean. Singh *et al*. (2015) described that the effect of different levels of S nutrition is found statistically significant on mung bean yield.

4.1.2.4. Available boron

The boron levels of the soil showed variations between the soil samples collected before planting and after harvesting that were collected from each plot receiving different treatments. Availability of boron content before the experiment was recorded 1.18 mg kg^{-1}; while, after harvesting the soil, available boron ranged from 0.405 to 1.505 mg kg^{-1} (low to medium) (Table 4). As a result of nutrient uptake by the mung bean crop, soil available boron content slightly increased in the treatments after harvest on most of the plots (Table 4). The lowest Av.B of 0.405 mg kg ha^{-1} was obtained from a plot planted with 0 kg NPSB ha^{-1} without inoculation and the highest was 1.505 mg kg ha^{-1} which was recorded from treatment receiving 100kg ha^{-1} NPSB fertilizer with inoculation at N-26 variety. The classification of boron content of the experimental sites could be rated as medium, and it is indicative of soil capable of significant yield responses to the application of the appropriate level of the nutrient (Jones, 2003). Thus, the number of seeds, number of pods and seed yield increased with residual boron availability (Verma *et al.,* 2004). Moreover, the number of seeds, number of pods and seed yield increased with residual boron availability (Verma *et al.,* 2004).

4.2. Effects of NPSB Rates and Rhizobium Inoculation on Phonological Parameters of Mung bean

4.2.1. Days to 50% flowering

Analysis of Variance (ANOVA) indicated that days to 50% flowering was significantly ($P<0.01$) influenced by the main effect of NPSB rates, variety and rhizobium inoculation as well as the two-way interaction of rhizobium inoculation with variety had significant at $P<0.05$(Table 4), while the remaining main as well as interactions effects had non-significant (Appendix Table 1). The variety N-26 treated with 0 kg NPSB ha^{-1} was earlier (55 days) to flower, which was without fertilizer application. The longest days to 50% flowering (59 days) was observed on variety NVL-1 without fertilizer application. The data obtained in this study revealed that the date of flowering was delayed based on varietal differences (Table 5). Variety N-26 was early flowering (60.08 days) which required the shortest days than NVL-1 which produce flower on longest days (62.5days) after planting (Table 5) which might be due to genetic differences as mung bean has high diversity in such phonological characters. According to Mwangi *et al.* (2021) stated that genetics of mung bean varied with their phonological traits. The application of NPSB rate significantly influenced the days required to reach 50% flowering in mung bean (Table 5). Increasing NPSB rate from 0 kg NPSB ha^{-1} to 150 kg NPSB ha^{-1} increased the number of days required to reach 50% flowering from 58.42 days to 63.67 days (Table 5). Thus, the maximum number of days to 50% flowering (63.67 days) was recorded at the highest rate of application of 150 kg ha^{-1} NPSB, while the minimum number of days to 50% flowering (58.42 days) was recorded from the control plots. This result showed that the fertilizer blend in different proportions of N, P, S and B might have prolonged the growth and development of the mung bean, thus increases the days to flowering. This result is similar with the finding of Sharma *et al*. (2013) showed that higher levels of N, P, S and B fertilizer significantly delayed days to 50% flowering and noted higher doses of fertilizer, particularly N, prolonged the growth period and resulted in delayed flowering.

Rhizobium inoculation significantly influenced the days required to reach 50% flowering in mung bean. Inoculated treatment had taken relatively longer days (62.71 days) to reach 50%

flowering than the un-inoculated treatment (59.875 days) to reach 50% flowering. The possible source for delayed flowering with the Rhizobium inoculation might be due to the point that inoculation enhanced nitrogen fixation (Table 6). Variety NVL-1with rhizobium inoculation had the longest days to reach 50% flowering (63.42 days) and the same variety without rhizobium inoculation (61.58) days to reach 50% flowering. This indicated that the seed inoculated to take the longest days to reach 50% of flowering on mung bean. On the other hand, variety N-26 with rhizobium inoculation (N1) (62.00) days to reach 50% flowering took longer time. Also, the same variety without rhizobium inoculation (N0) was (58.17) days to reach 50% flowering on mung bean (Table 5). This indicated that, it might be attributed to variation in the genetic makeup among cultivars/ re-lating to their inherent phenological setups (Mwangi *et al*., 2021).

Table 5. Interaction Effects of Rhizobium Inoculation and Varieties on Days to flowering

Treatments	Days to 50% flowering	
	Varieties	
Inoculants	NVL-1	N-26
R1	63.42 ^{a}	62.00^{b}
R0	61.58^{c}	58.17^{d}
LSD (0.05)	0.8	
CV (%)	7.5	

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD=Least significant difference, CV = Coefficient of variation

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Table 6. DF, PM and PH as Influenced by NPSB, Varieties and Rhizobium inoculation

Treatments	Days to flowering	Physiological maturity	Plant height
Fertilizers(NPSB kg/ha)			
0	58.42^{d}	74.33^{d}	38.83^{d}
50	60.92^{c}	76.17^{c}	39.83^{c}
100	62.17^{b}	79.00^{b}	41.83^{b}
150	63.67^{a}	84.4167^{a}	44.25^{a}
LSD (0.05)	1.09	1.24	0.90
Varieties			
NVL-1	62.5^{a}	79.208^{a}	40.29^{b}
N-26	60.08^{b}	77.75^{b}	42.08^{a}
LSD (0.05)	0.77	0.87	0.64
Inoculants			
R1	62.71^{a}	79.83^{a}	43.21^{a}
R0	59.87^{b}	77.12^{b}	39.17^{b}
LSD (0.05)	0.77	0.87	0.64
CV (%)	7.95	5.66	9.8

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD=Least significant difference, CV = Coefficient of variation; R0= without inoculant, R1= with inoculant ,date of flowering , PM= physiological maturity and PH plant height

4.2.2. Days to 90% maturity

Main effects of NPSB fertilize rates, variety and Rhizobium inoculation had significant ($p<0.01$) effect on days to 90% physiological maturity (Appendix Table 1). Furthermore, the interaction of NPSB rates with varieties had also significant ($p<0.05$) effect on days to 90% physiological maturity (Appendix Table 1). The application of 150kg ha^{-1} NPSB rate had the longest days to reach 90% physiological maturity (84.42 days), whereas with 0 kg ha^{-1}NPSB rate was the shortest days to reach 90% physiological maturity (74.33 days) which was without fertilizer application (Table 6). The result indicated that days to maturity were extended in response to the increased rates of NPSB fertilizer. The delay in days to maturity at highest NPSB rate could be due to the fact that N fertilization increases the vegetative growth of mung bean. Accordingly, maturity date prolonged following the increase in the rates of NPSB, which might be related to the role of N in the NPSB that enhanced vegetative growth. It is observed that N improved luxuriant vegetative growth, thereby delaying maturity in mung bean (Kawte and Mesfin, 2020).

Variety N-26 had the earliest days to reach 90% physiological maturity (77.75 days); while, variety NVL-1 had the longest days (79.21days) to reach 90% physiological maturity. This variation might be attributed by genotypic differences of the varieties. Phenological characteristics are genetically controlled, and individual variety has different growing habit, flowering and maturity days. The longest maturity days (85.00 days) was shown from interaction of 150kg ha^{-1} NPSB rate with NVL-1, whereas the earliest maturity date (81.00 days) was attained from N-26 with 150kg ha^{-1} NPSB fertilizer applied (Table 7). Thus, difference might be attributed by genotypic differences of the particular varieties-and rates of NPSB application. The result indicated that days to maturity were prolonged in response to the increased rates of NPSB and genotypic differences of the varieties (Mulu *et al.*, 2022).

Table 7. Interaction effect of NPSB fertilizer and Varieties on Mung bean Physiological maturity

Treatments	NPSB Fertilizers			
	0	50	100	150
Varieties				
NVL-1	74.17gh	75.00efgh	78.00^{cde}	85.00^{a}
N-26	72.33h	74.67fgh	77.17^{defg}	81.00^{bc}
LSD (0.05)	0.06			
CV (%)	5.58			

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD=Least significant difference, CV = Coefficient of variation

4.3. Combined Effect of NPSB Fertilizer, Varieties and Rhizobium Inoculants on Growth Parameters of Mung bean Crop

4.3.1. Plant height

Analysis of variance indicated that all main effect of NPSB fertilizer rate, variety and Rhizobium inoculation had significant ($P<0.01$) effect on plant height. Similarly, the two-way interaction effect of NPSB fertilizer and Rhizobium inoculation was also significant ($P<0.01$) on plant height. But, the others two and three-way interaction had a non-significant ($P<0.05$) effect on plant height (Appendix Table 1). The tallest plant height (46.00 cm) was recorded in the 150 kg NPSB ha^{-1} fertilizer rate with rhizobium inoculation, which was statistically at par with 100 kg

NPSB ha^{-1} fertilizer rate (44.83 cm). While, the shortest plant height (37.33cm) was recorded on 0 kg NPSB ha^{-1} rates and without rhizobium inoculation (Table 6).

The significant increase in plant height in response to combined application of NPSB rates with rhizobium inoculation might be due to the fact that nitrogen, phosphorus and sulfur nutrients are involved in vital plant functions and contribute to enhanced growth in the height of the crop. The increased P application rate in NPSB rates might be due to the maximum vegetative growth of the plants under higher P availability, N (in NPSB) can be helpful in improving growth and development of mung bean and Sulfur is also a major component of ferreoxin in chloroplast which is relevant for the proper photosynthetic activity. This result is in agreement with the finding of Taj *et al*. (1996) who reported an increase in plant height of mung bean in response to nitrogen and phosphorus application (20 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1}). Furthermore, the presence of boron in the blended fertilizer might have also significantly increased plant height due to its important role in the cell division and nitrogen absorption from the soil, enhancing plant growth eventually increases in the mung bean height. On another study, interaction of P and Rhizobium inoculant has brought significant effect on plant height of mung bean (Hussain *et al*., 2014).

Table 8. Plant height of Mung bean as Influenced by the Main effect of Varieties

Treatments	Plant height
Varieties	
N-26	42.1^{a}
NVL-1	40.3^{b}
LSD (5%)	0.098
CV (%)	9.76

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation

The tallest plant height (42.1cm) was observed on N-26 variety and the variety NVL-1 was recoded (40.3cm) which indicated that the two mung bean varieties have genetic variation. The difference of plant height was due to the genetic makeup of the varieties (Table 8). This result indicates that the varietal characteristics, individual variety have different growth habit (Islam *et al*., 2017).

Table 9. Interaction effect of NPSB fertilizer and Rhizobium inoculation on Plant height

	NPSB kg ha^{-1}			
	0	50	100	150
R1	40.33^{c}	41.67^{b}	44.83^{a}	46.00^{a}
R0	37.33^{e}	38.00^{de}	38.83^{d}	42.50^{b}
LSD (5%)	1.28			
CV (%)	9.8			

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation

4.3.2. Number of primary branches

All the main effects of NPSB fertilizer, varieties and rhizobium inoculation and the interaction of NPSB rates with rhizobium inoculation as well as interaction effect of NPSB * varieties * rhizobium inoculation were significant ($P<0.01$) on the number of primary branches per plant (Appendix Table 1). The highest branch number (5.20 and 5.17) was recorded from interaction of fertilizer NPSB at rate of 150 kg ha^{-1} with rhizobium inoculation and variety NV-1 & 150 kg ha^{-1} without rhizobium inoculation on N-26 variety respectively, whereas the lowest number of primary branch (3.90) was obtained from variety NVL-1 with no fertilizer and inoculation applied (Table 10). The increase in number of primary branches per plant with the increment of the rates of NPSB fertilizer with rhizobium inoculation for optimal symbiotic might be that nitrogen; phosphorus, sulfur and boron nutrients are involved in vital plant functions and contributed to enhanced growth in the height of the mung bean. Furthermore, the increased number of effective branches per plant in response to increased NPSB application rate indicates maximum vegetative growth of the plants under higher N and S availability, and P plays a key role in early root proliferation, which may increase the plant's nutrient uptake, resulting in increased vegetative growth (Muhammad *et al.*, 2016).

4.3.3. Number of secondary branches

The three-way interaction of NPSB fertilize rate*varieties*rhizobium inoculation had significant ($p < 0.05$) effect on number of secondary branch (Appendix Table 1). The highest number of secondary branches per plant (6.00) was recorded at 150 kg ha^{-1} NPSB fertilizer rate with rhizobium inoculation. On the other hand, the lowest number of secondary branches per plant (4.67) was recorded from 0 kg ha^{-1} NPSB rates (Table 10). The increase in number of secondary branches per plant in response to the increased NPSB application rate indicates maximum vegetative growth of the plants under higher N and S availability and P also, plays an essential role in early root production that might increase the nutrient up take of the plant, resulted in an increased vegetative growth. In agreement with this result, Wedajo (2015) reported higher number of secondary branches (9.15) with 50 kg P_2O_5 ha^{-1} over the control on soybean. Furthermore, a high level of P in the soil helps the uptake of other nutrients, which ultimately produces a healthy plant with the maximum productive branches of the crop (Hamza *et al*., 2016).

4.3.4. Nodule number

The analysis of variance (ANOVA) showed that all the main effect, the two and three-way interaction had significant ($P \leq 0.01$) effect on nodule number per plant of mung bean (Appendix Table 1). The highest number of nodules (20.7) per plant of mung bean was observed from the interaction effect of Rhizobium inoculation with NPSB fertilizer of 150 kg ha^{-1} for variety N-26, while variety NVL-1 without inoculation at 0 kg NPSB rate has produced the lowest number of nodules numbers (2.07) (Table 10). The combination of rhizobium inoculation with NPSB rates with mung bean varieties increased the production of numbers of nodules per plant. The highest value might be due to P combined with rhizobium inoculation playing crucial role in utilization of S leading to increased nodule numbers which facilitate N fixation process. Rhizobium inoculation increased the number of nodules per plant compared to the un-inoculated treatment, which could be attributed to the fact that the inoculated bacteria strain had good nodulation and nitrogenase enzyme present in an inoculated which causes nodule formation and rhizobacteria are competent bacteria in the rhizosphere that can multiply and colonize plant roots at all stages of plant growth. In line with this result, several finding had reported that application of P along with Rhizobium inoculate influenced nodulation and N fixation of legume crops (Saini *et al*., 2004).

Hussain *et al*. (2014) also described that interaction of P with Rhizobium strains increased nodule number of mung bean.

Table 10. effect of NPSB, Varieties and Rhizobium inoculation on Branches and Nodules

Treatments	NPSB fertilizer							
	0		50		100		150	
Inoculants	R1	R0	R1	R0	R1	R0	R1	R0
Varieties								
	Number of primary branch per plant							
NVL-1	4.27^{de}	3.90^{f}	4.00^{f}	4.27^{de}	4.33^{d}	4.33^{d}	5.20^{a}	4.07^{ef}
N-26	4.60^{bc}	4.00^{f}	4.33^{d}	4.27^{de}	4.60^{bc}	4.47^{cd}	4.73^{b}	5.17^{a}
LSD (0.05)	0.26							
CV (%)	12.9							
	Number of secondary branch per plant							
NVL-1	5.20^{fgh}	4.67^{k}	4.80^{jk}	4.90^{ij}	5.27^{efgh}	5.47^{de}	6.00^{a}	5.33^{efg}
N-26	5.33^{efg}	5.07^{hi}	5.17^{gh}	5.40^{def}	5.40^{def}	5.60^{cd}	5.73^{bc}	5.90^{ab}
LSD (0.05)	0.23							
CV (%)	11.5							
	Number of nodules per plant							
NVL-1	4.47^{gh}	2.07^{i}	6.73^{gh}	2.27^{i}	7.67^{e}	4.60^{gh}	8.73^{d}	6.73^{f}
N-26	5.23^{g}	2.60^{i}	9.00^{d}	4.13^{h}	14.87^{b}	6.33^{f}	20.70^{a}	11.07^{c}
LSD (0.05)	0.77							
CV (%)	6.31							
	Nodules volume per plant							
NVL-1	0.50^{g}	0.30^{h}	0.87^{f}	0.37^{gh}	1.17^{de}	1.13^{e}	1.57^{b}	1.33^{c}
N-26	1.27^{cde}	0.37^{gh}	1.53^{b}	0.77^{f}	1.50^{b}	1.17^{de}	2.17^{a}	1.30^{cd}
LSD (0.05)	0.15							
CV (%)	8.55							
	Effective nodule per plant							
NVL-1	2.67^{hi}	1.00^{j}	5.33^{de}	1.67^{ij}	6.00^{d}	3.33^{gh}	7.33^{c}	5.00^{def}
N-26	4.33^{efg}	1.67^{ij}	8.33^{c}	2.33^{hi}	11.00^{b}	4.00^{f}	16.33^{a}	7.67^{c}
LSD (0.05)	1.18							
CV (%)	12.95							

Means followed by the same letter are not significantly different at P > 0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation

4.3.5. Nodule volume

The three-way interaction analysis of variance revealed that the rate of NPSB by varieties with Rhizobium inoculation had significant ($p<0.05$) effect on nodule volume of mung bean. All the main and two-way interaction effects were significant ($P<0.01$) effects on the nodule volume per plant of mung bean (Appendix Table 2). The highest nodule volume per plant (2.17 ml) of mung bean was recorded from the interaction of 150 kg ha^{-1}fertilizer NPSB rates with Rhizobium strain of the variety N-26. The lowest (0.30 ml) nodule volume per plant was obtained from 0 kg rate of NPSB ha^{-1} without Rhizobium strain on variety NVL-1 (Table 10). The highest value from 150 kg ha^{-1} fertilizer NPSB rates with Rhizobium strain might be due to combination effect of high nitrogen fixation process performed by activity of P and formation of ferrodoxin by S and Rhizobium strain there by increasing volume of nodules. Thus, this study is in line with finding of Arima *et al*. (2000) and Ali *et al*. (2004) who reported that the higher the nodule volume was reported with increase the rate of NPSB in combination with Rhizobium strain.

4.3.6. Number of effective nodule

The analysis of variance indicated that the three-way interaction effect of NPSB fertilizer application by varieties with Rhizobium inoculation had significant ($P<0.05$) effect on number of effective nodules per plant. Similarly, all the main effect and the two-way interaction effect had significant ($P<0.01$) effect on number of effective nodules per plant in mung bean (Appendix Table 2). The highest number of effective nodules per plant (16.33) was recorded at the rate of 150 kg NPSB ha^{-1} with Rhizobium inoculation on variety N-26. While, the lowest number of effective nodules per plant (1.00) was recorded at the rate of 0 kg NPSB ha^{-1} rate without inoculation on variety NVL-1 (Table 10). The increase in effective number of nodules may be due to application of nitrogen and sulfur fertilizer that stimulate nodule formation and also enhance yield of pulse including varieties. As a result, their interaction increased the rate of nitrogen fixation that improved the effectiveness of nodules. The current finding is in line with Bashir *et al*. (2011) who stated that phosphorus plays a vital role in increasing plant tip and root growth, decreasing the time needed for developing nodules to become active (effective) for the benefit to the host legume.

4.3.7. Nodule fresh weight

The analysis of variance showed that the two-way interactions of varieties with Rizobium inoculation had significant (P<0.01) effect on nodule fresh weight (Appendix Table 1). Consequently, the highest (2.21g) number of nodules fresh weight was recorded from variety N-26 with rhizobium inoculation, while the lowest number of nodules fresh weight (1.0g) were obtained from NVL-1 without Rhizobium inoculation (Table 11). This could be the differential response of genotype to the interaction effect of phosphorus fertilizer rate and Rhizobium inoculates that eventually lead to higher fresh weight of total nodules through increased BNF (Biological nitrogen fixation) availability. In agreement with this study, Beza (2017) reported that P application with Rhizobium strains individually or in combination affected root development, nodule weight per plant and nitrogen fixation parameters.

Table 11. effect of Varieties and Rhizobium inoculation on Nodule fresh weight and Dry weight

Treatments	**Varieties**	
	NVL-1	N-26
Inoculants	Nodule fresh weight per plant	
R1	1.48^{b}	2.21^{a}
R0	1.00^{c}	1.35^{b}
LSD (0.05)	0.15	
CV (%)	12.26	
	Nodule dry weight per plant	
R1	0.16^{b}	0.28^{a}
R0	0.09^{d}	0.11^{c}
LSD (0.05)	0.012	
CV (%)	9.24	

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation

4.3.8. Nodule dry weight

The analysis of variance revealed that the two-way interaction of varieties with Rhizobium inoculate were significant (P<0.01) on the dry weight of nodules per plant in mung bean. However, the left over two-way interaction of rate NPSB fertilizers with varieties and the three-way interaction rate of NPSB fertilizers by varieties by Rhizobium inoculates had non-significant difference on nodule dry weight of mung bean (Appendix Table 1). The highest (0.37g) dry weight of nodules per plant was obtained from Rhizobium inoculation combined with the variety N-26, while the lowest (0.09g) nodules dry weight value was obtained on variety NVL-1 (Table 11). Probably, due to the positive role of Sulfur in NPSB in promoting nodulation and enhancement of photosynthesis occurred in plants. Similarly, different authors reported that the dry weight of nodules increased with Rhizobium inoculation (Sipai *et al*., 2016).

4.3.9. Shoot fresh weight

The analysis of variance showed that the three-way interaction effect of different rate of NPSB fertilizer with varieties with rhizobium inoculation exhibited significant ($P<0.05$) effect on shoot fresh weight. Similarly, the main effects of rate of NPSB, varieties and inoculation had significant ($P<0.01$). While, all the other two-way interaction effect had non-significant on shoot fresh weight (Appendix Table 2).

Table 12. effect of NPSB, Varieties and Rhizobium inoculation on Shoot fresh and Dry weights

Treatments	NPSB **Fertilizers**							
	0		50		100		150	
Inoculants	R1	R0	R1	R0	R1	R0	R1	R0
Varieties								
	Shoot fresh weight per plant (g)							
NVL-1	33.00^{def}	27.33^{g}	35.00^{cdef}	32.00^{ef}	35.67^{cdef}	31.67^{f}	41.67^{b}	36.33^{cd}
N-26	35.33^{cdef}	31.67^{f}	36.00^{cde}	34.00^{cdef}	37.67^{bc}	33.67^{cdef}	47.00^{a}	41.33^{b}
LSD (0.05)	4.14							
CV (%)	6.98							
	Shoot dry weight per plant (g)							
NVL-1	6.20^{k}	6.40^{k}	8.13^{g}	6.53^{k}	9.13^{e}	7.13^{ij}	9.83^{d}	8.66^{f}
N-26	7.77^{hi}	6.23^{k}	10.67^{c}	7.17^{j}	11.00^{c}	7.80^{gh}	13.00^{a}	11.67^{b}
LSD (0.05)	0.35							
CV (%)	2.45							

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation

The highest shoot fresh weight (47.00g) per plant was recorded with the application of 150 kg NPSB ha^{-1}with Rhizobium inoculation on variety N-26. While, the lowest shoot fresh weight (27.33g) was recorded at 0kg NPSB ha^{-1} application and without rhizobium inoculation on NVL-1 (Table 12). Seed inoculation significantly increased the growth parameters of mung bean (Khan and Kounsar, 2000). Moreover, Delic *et al*. (2019) reported that all investigated characteristics of shoot weight of mung bean significantly increased due to seed inoculation with particular Rhizoidal strains.

4.3.10. Shoot dry weight

The analysis of variance showed that almost all the main effect, two and three-way interaction of varieties, rhizobium inoculation and different rates of NPSB fertilizer showed significant ($P<0.001$) variation on shoot dry weight of mung bean per plant (Appendix Table 2). The highest shoot dry weight (13.00 gram per plant) was recorded with application of 150 kg NPSB ha^{-1} with rhizobium inoculation from variety N-26. While, the lowest (6.20g) shoot dry weight was recorded without application of NPSB and without rhizobium inoculation (control) from variety NVL-1 (Table 12). The increase in shoot dry weight could be due to the presence of rhizobium inoculation, which promotes vegetative growth. In line with this finding, several authors also reported the positive effect of S application promotes in shoot dry weight (Hussain *et al*., 2011 and Kesare, 2014). Similarly, the increase in number of branches per plant might be importance of P for cell division activity, leading to the increase of plant height and number of branches and consequently increased the plant dry weight (Tesfaye *et al*., 2007).

4.3.11. Root fresh weight

The analysis of variance showed that the main effect of rate of NPSB, varieties and inoculation had significant ($P<0.01$) effect on root fresh weight. As well as the two-way interaction, effects of rate of NPSB with rhizobium inoculation had significant ($P<0.05$) effects of root fresh weight on mung bean varieties. However, the other interaction had non-significant effects of root fresh weight on mung bean. The highest (3.57g) root fresh weight of mung bean recorded from the interaction of 150kg ha^{-1} NPSB rate of fertilizer with rhizobium inoculation while, the lowest (2.25 g) was recorded at 0 kg ha^{-1} NPSB rate of fertilizer without rhizobium inoculation. The maximum root fresh weight was observed on N-26 variety (3.15g) and the variety NVL-1 was recorded (2.87g) which indicated that the tow mung bean varieties have genetic variation. The difference of root fresh weight was due to the genetic makeup of the varieties (Table 13). These results indicate that the varietal characteristics, individual variety have different growth habit (Islam *et al.*, 2017).

Table 13. Root fresh weight of Mung bean as Influenced by the Main effect of Varieties

Treatments	Root fresh weight
Varieties	
N-26	3.15a
NVL-1	2.87b
LSD (5%)	0.134
CV (%)	7.53

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation

4.3.12. Root dry weight

The analysis of variance (ANOVA) showed that all the main effects and the two way interaction of different rates of NPSB fertilizer with varieties showed significant ($P<0.01$) variation for root dry weight of mung bean per plant; while, the rest had non-significant effects of root dry weight on mung bean (Appendix Table 2). The highest (0.61 g) root dry weight of mung bean was recorded from interaction of 150kg ha^{-1} rate NPSB fertilizer with variety N-26. Whereas, the lowest (0.47 g) root dry weight was obtained from control (Table 14).

Table 14. Interaction effect of NPSB and Rhizobium inoculation on Root fresh weight and RDW

Treatments	**NPSB Fertilizers (kg/ha)**			
	0	50	100	150
Inoculants	Root fresh weight per plant (g)			
R1	2.95^{c}	3.25^{b}	3.45^{ab}	3.57^{a}
R0	2.25^{d}	2.43^{d}	2.75^{c}	3.43^{ab}
LSD (0.05)	0.267			
CV (%)	7.53			
	Root dry weight per plant (g)			
R1	0.51^{d}	0.54^{e}	0.60^{b}	0.63^{a}
R0	0.44^{g}	0.49^{f}	0.53^{de}	0.57^{c}
LSD (0.05)	0.02			
CV (%)	3.29			
Varieties	Root dry weight per plant (g)			
NVL-1	0.50^{d}	0.49^{de}	0.54^{c}	0.59^{b}
N-26	0.47^{e}	0.51^{d}	0.58^{b}	0.61^{a}
LSD (0.05)	0.02			
CV (%)	3.29			

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation, RDW= root dry weight

The highest (0.627 g) root dry weight of mung bean was recorded from interaction of 150kg ha^{-1} rate NPSB fertilizer with Rhizobuim inoculation. Whereas the lowest (0.44g) root dry weight was recorded at control. The highest value might be due to that application of extractable S in NPSB and the Rhizobium strain enhanced N and P uptake, motivate photosynthetic activity and synthesis of chloroplast protein resulting in higher root dry matter production. Similarly, seed inoculation with Rhizobium bacteria increased, dry weight of root and shoot of legume crops (Sharma, 2001). Muhammad *et al*. (2016) also described that inoculation with rhizobium increased root dry weight than the control in mung bean.

4.4. Interaction Effects of NPSB Fertilizer, Varieties and Rhizobium Inoculation on Yield and Yield Components of Mung bean

4.4.1. Number of seeds per pod

The analysis of variance exhibited that all the main effects were significantly ($p<0.01$) influence the number of seeds per pod. Besides, the two-way interaction effect of NPSB fertilizer with Rhizobium inoculation, and varieties with Rhizobium inoculation had significant effect ($p<0.05$) on number of seeds per pod. However, the three-way interaction effect had no significant effect on number of seeds per pod (Appendix Table 3). The highest (14.17) seed number per pod of mung bean was recorded from interaction of 150kg NPSB ha^{-1} fertilizer rate with Rhizobium strain, while the lowest (10.50) was obtained from control treatments (Table 15). In this study, the highest seed number per pod might be due to bio-fertilizers play an important role in increasing availability of nitrogen and phosphorus besides increase in biological fixation of atmospheric nitrogen and enhance phosphorus availability to crop (Mulu *et al.,* 2022).

Table 15. Interaction effect of Rhizobium inoculation and Varieties on Number of seed per pod

Treatments	Number of seeds per pod	
	Varieties	
Inoculants	N-26	NVL-1
R1	12.33^{d}	12.00^{de}
R0	11.00^{ef}	10.00^{f}
LSD (0.05)	1.19	
CV (%)	5.3	

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation

Therefore, introduction of efficient strain of Rhizobium in soil enhances the quality of soil by providing more nitrogen fixation and which may be helpful in boosting up production (Pathak and Hararik, 2001). Similarly, the combination of photosynthesis function of metabolic energy ability of S and nitrogen fixing ability of rhizobium strain contributed (Sadeghipour *et al*., 2010).

Similarly, the variety N-26 with Rhizobium inoculation gave highest (12.33) number of seed per pod and NVL-1 variety with Rhizobium inoculation it gave 12.00 (12.00) number of seed per pod while the lowest (10.00) number of seeds per pod on NVL-1 variety without Rhizobium inoculation (Table 15). These results indicate that the varietal characteristics, individual variety have different growth habit (Islam *et al*., 2017).

4.4.2. Harvest index

Analysis of variance indicated that the two-way interaction effect of NPSB fertilizer with varieties and NPSB fertilizer with Rhizobium inoculation had also a significant ($P<0.05$) effect on the harvest index while other effects had non-significant effect on the harvest index (Appendix Table 3). The application rate of 150 kg NPSB ha^{-1} with Rhizobium inoculation produced the highest (0.48) harvest index, while the lowest harvest index (0.42) was recorded at 0 kg NPSB ha^{-1} without Rhizobium inoculation. Similarly, the maximum harvest index (0.49) was obtained from N-26 variety at NPSB rate of 150 kg ha^{-1}, which was followed by the same variety N-26 (0.47) at rate of 100 kg NPSB ha^{-1} (Table 16). Harvest index had relationship with grain yield and above ground biomass yield, that the highest harvest index was the result of greater grain yield. The highest harvest index might be also due to the influence of increased rate of NPSB rate on translocation of dry matter from vegetative to grain part to economic yield (Mulu *et al.*, 2022). This might be due to the variety N-26 with the high number of total pods per plant and yield that in turn resulted in to higher harvest index. Malik *et al.* (2003) also reported an increase in harvest index of mung bean in response to addition of N and P.

Table 16. effect of NPSB and Rhizobium inoculation on NSPP, HI and AGBMY

Treatments	**NPSB Fertilizers**			
	0	50	100	150
Inoculants	Number of seeds per pod			
R1	12.17e	12.83^{cd}	13.50^{b}	14.17^{a}
R0	10.50g	11.50^{f}	12.50^{de}	13.17^{bc}
LSD (0.05)	0.39			
CV (%)	7.9			
Inoculants	Harvest Index			
R1	0.442^{d}	0.450^{cd}	0.472^{ab}	0.483^{a}
R0	0.420^{e}	0.427^{e}	0.425^{e}	0.463^{bc}
LSD (0.05)	0.014			
CV (%)	2.61			
	Above ground dry biomass yield (Kg/ha)			
R1	3133.33^{e}	3866.67^{c}	4166.67^{ab}	4241.67^{a}
R0	3033.33^{e}	3483.33^{d}	3933.33^{c}	4091.67^{b}
LSD (0.05)	108.08			
CV (%)	13.6			

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation, HI= harvesting index ,NSPP= nember of seed per pod and AGBMY=above ground biomass yield .

4.4.3. Above ground dry biomass

The main effect of blended NPSB rate, varieties and Rhizobium inoculation was significant ($P<0.01$) and the two-way interaction effect of NPSB rate with Rhizobium inoculation also showed significant ($P<0.05$) effect on above ground dry biomass yield of mung bean (Appendix Table.3). But, the others two and the three-way interaction had non-significant ($p<0.05$) effects on above ground dry biomass yield of mung bean (Appendix Table 3). The highest (4241.67 kg ha^{-1}) above ground dry biomass was observed from a combination of NPSB rate at 150 kg ha^{-1} with Rhizobium inoculation whereas, the lowest (3033.33kg ha^{-1}) obtained from the control treatments (Table 16). This could be due to the cumulative effect of NPSB and inoculation in root, vegetative and reproductive growth and development of mung beans.

Therefore, higher biological yield was obtained due to vigor stands, good canopy development and dry matter production in response to NPSB fertilization and Rhizobium bacteria. This result is in agreement with finding of Girma (2009) and Mulu *et al.* (2022) who reported a significant increment in biological yield of common bean with increased rates of NP fertilizers from 0 N kg, 0 kg P_2O_5 to 27 N, 69 kg P_2O_5 kg ha^{-1} (150 kg DAP). Similarly, Nuru Seid (2020) reported that the total dry matter production per plant increased significantly from 12.0 to 16.03 g due to increased nitrogen application from 40 to 120 kg N ha^{-1}.

Table 17. Rhizobium inoculation, Varieties and NPSB effects NSPP, HI and AGBMY

Treatments	Number of seeds per pod	Harvest Index	Above ground dry biomass yield
Fertilizers			
0	11.33^d	0.431^c	3083.3^d
50	12.17^c	0.438^c	3675.0^c
100	13.00^b	0.448^b	4050.0^b
150	13.67^a	0.473^a	4166.7^a
LSD (0.05)	0.66	0.0098	76.43
Varieties			
NVL-1	12.13^b	0.438^b	3606.25^b
N-26	12.96^a	0.458^a	3781.25^a
LSD (0.05)	0.20	0.0069	54.04
Inoculants			
R1	11.92^b	0.462^a	3852.1^a
R0	13.17^a	0.434^b	3635.4^b
LSD (0.05)	1.22	0.007	54.04
CV (%)	7.9	2.61	13.6

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation HI= harvesting index ,NSPP= nember of seed per pod and AGBMY=above ground biomass yield .

The highest (3781.25 kg ha^{-1}) above ground biomass was observed from N-26 variety whereas, the lower (3606.25kg ha^{-1}) obtained from the NVL-1 variety. The increased above ground biomass yield of varieties could be attributed to genotypic differences in varieties ability to increased plant height, number of pods per plant, and general vegetative growth of the plants, all of which contributed to higher above ground dry biomass yield.

4.4.4. Number of seeds per plant

The analysis of variance revealed that the interaction effects of NPSB fertilizer and seed inoculation were significantly ($P<0.05$) influenced the number of seeds per plant. However, the other two and three-way interaction rate of NPSB with varieties with Rhizobium inoculation had non-significant ($P<0.05$) effect on number of seeds per plant (Appendix Table 3). The highest (607.33) seeds number per plant of mung bean was recorded from interaction of 150kg ha^{-1} NPSB fertilizer with Rhizobium strain, whereas the lowest (342.33) seed number per plant was obtained from 0 kg ha^{-1}NPSB fertilizer without Rhizobium strain (Table 18).

Table 18. Interaction effect of NPSB and Rhizobium inoculation on Number of seed per plant

Treatments	**NPSB Fertilizers**			
	0	50	100	150
Inoculants	Number of seeds per plant			
R0	342.33^{g}	428.33^{e}	454.50^{d}	546.50^{b}
R1	396.17^{f}	471.33^{c}	555.67^{b}	607.33^{a}
LSD (0.05)	15.98			
CV (%)	7.93			

Means followed by the same letter are not significantly different at $P>0.05$ level of probability, LSD= Least significant difference, CV = Coefficient of variation

This increment in number of seeds per plant with increasing NPSB fertilizer application rates under seed inoculation might be due to the fact that P is an essential component in seed formation. Furthermore, the supply of adequate nutrients might have facilitated the vegetative growth, which might, in turn, have contributed to the production of higher number of seed per plant. In line with this, Mulu (2019) and Mulu *et al.* (2022) also observed significant variation in number of seeds per plant due to the interaction effect of NPS and mung bean varieties.

The analysis of variance (ANOVA) showed that the main effect of varieties had significant effect on number of seeds per plant ($p<0.05$) (Appendix Table 3). The highest number (488.8) of seeds per plant was recorded from variety N-26. Whereas, the least (461.8) number of seeds per plant was recorded for variety NVL-1. This indicates that the trait is mainly controlled by genetic factors than the management, and this could be further linked to differences in seed size among the varieties. The differences of number of seeds pod_{-1} was due to the genetic makeup of the varieties (Kotwal and Prakash, 2007).

Table 19. Number of Seeds per plant as Influenced by the Main effect of Varieties

Treatments	Number of seeds per plant
Varieties	
N-26	488.8a
NVL-1	461.8b
LSD (5%)	0.079
CV (%)	7.93

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation

4.4.5. Number of pods per plant

The analysis of variance (ANOVA) showed that the interaction of NPSB fertilizer rates, varieties and with Rhizobium inoculation had significant effect on number of pods per plant ($p<0.05$). However, the two-way interaction effect of NPSB fertilizer rates with variety does not show a significant difference for number of pods per plant (Appendix Table 3). Variety N-26 with 150 kg NPSB rate ha-1 with Rhizobium inoculation produced significantly the highest number of pods per plant (46.33), which was statistically at par with the application of 100 kg NPSB rate ha-1 with Rhizobium inoculation (45.67) the same variety. While, the lowest (22.00) number of pods per plant was obtained from the control plot without Rhizobium inoculation by variety NVL-1 (Table 20). The growth behavior of legume crops including mung bean can be determined by number of pods per plant. The increase in number of pods per plant with the increased NPSB rates might be due to adequate availability of N, P, S and B and inoculated seed 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 pod per plant. In agreement with the result of Mulu *et al.* (2022) and Moniruzzaman *et al*. (2008) reported significant effect of N fertilizers on pod production per plant of bean was resulted in the increment of number of pods per plant, inoculation with Rhizobium bacteria significantly increased the number of pods per plant. Plants that were inoculated with Rhizobium showed about 9% more pods per plant than non-inoculated plant. Number of pods per plant of mung bean increased with rhizobuim inoculate in association with P application (Hussain *et al.*, 2014; Malik *et al.*, 2002 & 2003; Muhammad *et al.*, 2016; Mulu *et al.*, 2022). Moreover, Habtamu (2015) also described that combined application of NP fertilizer with rhizobium had highly significant effect on the number of pods per plant of mung bean.

4.4.6. Hundred Seed weight

The analysis of variance revealed that interaction effects of NPSB rates of fertilizer, varieties and Rhizobium inoculation had significant ($P \leq 0.05$) effect on hundred seed weight of mung bean; and also the rest interaction effect significantly varied at ($p<0.01$) (Appendix Table 3). The highest hundred seeds weight (7.50 g) was recorded at 150 kg of NPSB rate ha^{-1} application with Rhizobium inoculation from variety N-26, while the smallest hundred seeds weight (5.73g) and (5.63g) were recorded at 0 kg NPSB rate ha^{-1} without rhizobium inoculation from variety N-26 and NVL-1, respectively (Table 19). This might be that the higher NPSB fertilizers rate had high influence on nutrient translocation from plant biomass to seed, while minimum score (5.63 g) was recorded from variety without inoculation at the rate of 0 kg ha^{-1} NPSB rate of fertilization. This result in line with the result of Mulu *et al.* (2022) who reported that significant variation was observed with the interaction of NPS with variety on hundred seed wrights. Nutrient use efficiency by crop was enhanced at optimum level of N, P, S and B since grain weight indicates the amount of resource utilized during critical growth periods. In line with this result Basu and Bandyopadhyay (1990) reported that in mung bean, the number of pods per plant, seeds per pod and 100 seeds weight were increased with increasing N rates up to 30 kg N ha$^{-1.}$ Similarly, Tesfaye Dejene (2015) also reported that 100 seed weight in common bean increased with increase in P fertilizer application (69 kg ha^{-1}).

Table 20. effect of NPSB, Varieties and Rhizobium inoculation on NPPP, HSWPP and Grain yield

Treatments	NPSB Fertilizers							
	0		50		100		150	
Inoculants	R1	R0	R1	R0	R1	R0	R1	R0
Varieties								
	Number of pods per plant							
NVL-1	28.00^{g}	22.00^{h}	35.67^{e}	29.33^{fg}	41.00^{c}	34.67^{e}	42.67^{b}	35.67^{e}
N-26	29.67^{f}	28.00^{g}	38.33^{d}	35.67^{e}	45.67^{a}	39.00^{d}	46.33^{a}	42.33^{bc}
LSD (0.05)	1.41							
CV (%)	14.35							
	Hundred seeds weight							
NVL-1	6.23^{h}	5.63^{i}	6.63^{f}	6.27^{gh}	6.87^{cd}	6.30^{g}	7.07^{b}	6.80^{de}
N-26	6.67^{ef}	5.73^{i}	6.73^{def}	6.40^{g}	7.13^{b}	6.67^{ef}	7.50^{a}	7.00^{bc}
LSD (0.05)	0.15							
CV (%)	15.1							
	Grain yield (Kg/ha)							
NVL-1	1373.10^{k}	1269.87^{i}	1672.23^{g}	1422.50^{j}	1859.37^{d}	1611.20^{h}	1997.63^{b}	1825.60^{de}
N-26	1403.60^{jk}	1290.37^{i}	1805.20^{e}	1555.33^{i}	2078.90^{a}	1737.90^{f}	2105.77^{a}	1955.83^{c}
LSD (0.05)	40.44							
CV (%)	5.44							

Means followed by the same letter are not significantly different at P>0.05 level of probability, LSD= Least significant difference, CV = Coefficient of variation HSWPP= hundred seed weight per plant and NPPP= number of pod per plant

4.4.7. Grain yield

The analysis of variance showed that the three-way interaction effect of NPSB rate, varieties and Rhizobium inoculation was significantly ($p<0.05$) affected grain yield of mung bean (Appendix Table 3). The highest grain yield (2105.77 kg ha^{-1}) was obtained from interaction effect of NPSB rate of 150 kg ha^{-1} with Rhizobium inoculation on variety N-26 and this was statistically at par with NPSB rate of 100 kg ha^{-1} with rhizobium inoculation grain yield (2078.90 kg ha^{-1}) of variety N-26; while, the lowest grain (1269.37 kg ha^{-1}) was obtained at 0 NPSB rate application and without inoculation on variety NVL-1 (Table 19). The grain yield increases might be due to the increased N, P and S availability and N-fixation and genotypic nutrient use efficiency. This result is similar with the result of Mulu *et al*. (2022) who reported that significant difference was observed with the interaction of NPS with varieties of mung bean on grain yield. In line with this result, Fatima *et al*. (2007) also reported that a mixture of Rhizobium strains with phosphorus recorded higher seed yield of soybean over inoculate without phosphorus. According to Khan *et al.* (2008) Rhizobium inoculum combined with varying levels of N fertilizer showed significant difference on yield of mung bean.

4.5. Economic Analysis

The parietal budget analysis was used to identify treatments with the optimum return for the farmer’s investment to indicated economic profitability of the farm. The results of the partial budget analysis for NPSB fertilizer rate as compared to inoculate and their combination effect on nodulation, growth and yield response of mung bean. The highest gross farm gate benefit 113,711.58 ETB ha^{-1} was gained from yield obtained at combined effect of 150kg NPSB ha^{-1} with rhizobium inoculates from variety N-26 and the second gross benefit, 112,260.6ETB was obtained from interaction effect of 100kg NPSB ha^{-1} with rhizobium inoculation from variety NVL-1 (Table 20). Therefore, the marginal rate of return was done based on a treatment to be considered as worthwhile to farmers, that is 50% and 100% marginal rate of return (MRR) is the minimum acceptable rate of return (CIMMYT, 1988). Hence, it is important to compare treatments to remove undesirable treatments in view of economic profitability rather than only looking at the highest grain yield, because it may not be attractive if they required very much higher cost. Therefore, the highest net benefit was 108,600.6 ETB ha^{-1} obtained at plot treated with 100kg NPSB ha^{-1} + Inoculate with variety N-26 in combination. The adoption of this treatment would give an additional gain of, 10130 % from every Birr invested in mung bean production. While the second highest 95,520.8 ETB ha^{-1} net benefit with additional gain of 7396.1 % from every Birr invested was obtained at interactive application of 50 kg NPSB ha^{-1} + with inoculation from variety N-26 (Table 16). In agreement with this result, Shah *et al*. (2011) reported that the maximum rate of return (446.21%) was recorded from the plots in which 120 kg N ha^{-1} was applied whereas the minimum rate of return (296.67%) was noted from the unfertilized plots. Therefore, interaction effect of 100 kg NPSB ha^{-1} + Inoculate was more economically attractive than all other treatment (Table 20). It has the highest return to the money invested in its production; it maximized profit and output and minimized costs (Table 16). All interaction effect from rate of fertilizer, inoculate and variety were economically viable and had positive marginal rate of returns.

The economic analysis has led to 100 kg NPSB ha^{-1} + inoculation with variety N-26 is suitable for potential adoption by farmers if additional study required to be undertaken on the same experiment to confirm for further use. Generally, significant maximum grain yields were obtained from 100kg NPSB ha^{-1} blended fertilizer interacted with Inoculate and variety as well as it had maximum marginal rate of return. From an economic point of view, the highest net benefit of 95520.8 ETB ha^{-1} was gained from variety N-26 grown on plots receiving 100 kg NPSB ha^{-1} + inoculation. Thus, based on the current findings, it can be concluded that growing rhizobium inoculated variety N-26 at 100 kg NPSB ha^{-1} can ensure better yield with the highest economic return for the farmers in the study area.

Table 21. Economic analysis of the response of Varieties for NPSB rates and Rhizobium inoculation

Treatment combination				Grain yield				Variable cost			Net Benefit		Benefit ratio
Varieties	inoculation	Fert	UAGY/ kg/ha-1	AGY/ Kg/ha-1	GFB (ETB ha-1	Fert Cost ETB ha-1	Inoc	Fert app.	Inoc app	TVC	NB	MRR %	B:C
NVL-1	without	0	1269.87	1142.88	68572.8	0	0	0	0	0	68572.8	D	
	with	0	1373.10	1235.79	74147.4	0	100	0	80	180	73967.4	2997	410.93
	without	50	1422.50	1280.25	76815	1700	0	80	0	1780	75035	66.725	42.154
	with	50	1672.23	1505.005	90300.3	1700	100	80	80	1960	88340	7391.7	45.07
	without	100	1611.20	1450.08	87004.8	3400	0	80	0	3480	83524.8	D	24.001
	with	100	1859.37	1673.433	100405.98	3400	100	80	80	3660	96745.98	494.47	26.433
	without	150	1825.60	1825.60	98582.4	5100	0	80	0	5180	93402.4	D	18.031
	with	150	1997.63	1797.867	107872.02	5100	100	80	80	5360	102512.02	339.18	19.125
N-26	without	0	1290.37	1161.33	69679.8	0	0	0	0	0	69679.8	D	-
	with	0	1403.60	1263.24	75794.4	0	100	0	80	180	75614.4	3297	420.08
	without	50	1555.33	1399.797	83987.82	1700	0	80	0	1780	82207.82	412.08	46.184
	with	50	1805.20	1624.68	97480.8	1700	100	80	80	1960	95520.8	7396.1	48.735
	without	100	1737.90	1564.11	93846.6	3400	0	80	0	3480	90366.6	D	25.967
	with	100	2078.90	1871.01	112260.6	3400	100	80	80	3660	108600.6	769.4	29.6722
	without	150	1955.83	1760.247	105614.82	5100	0	80	0	5180	100434.82	D	19.3889
	with	150	2105.77	1895.193	113711.58	5100	100	80	80	5360	108351.58	D	21.245

UAGY= Unadjusted grain yield, AGY= adjusted grain yield, GFB = gross field benefit, TVC = total variable costs, NB = net benefit; MRR = marginal rate of return; ETB ha-1 = Ethiopian Birr per hectare;

5. SUMMARY AND CONCLUSSION

Management of fertilizer and Rhizobium inoculation were important factor that greatly influences the growth and yield of Mung bean crop. Likewise, an appropriate management practice that combines high yielding varieties with balanced fertilizers with Rhizobium inoculation were lacking in the study area. Use of combination of appropriate variety, NPSB application and Rhizobium inoculation are the major agronomic practices that can improve the productivity of mung bean. Thus, a field experiment was conducted at Misirak Meskan District in 2021/22 with the objectives of assessing the response of mung bean varieties to rate of NPSB fertilizer and rhizobium inoculation, to evaluate the economic feasibility of rate of NPSB fertilizer and their interaction effects on selected soil physiochemical properties, growth, nodulation, and yield and yield related components. Two mung bean varieties (N-26 and NVL-1), with and without inoculation and four rates of NPSB (0, 50, 100 and 150 kg ha^{-1}) fertilizer were tested in factorial arrangement in RCBD with three replications.

Results of soil samples collected before planting revealed that the experimental field was clay loam in texture and medium in reaction (pH= 6.83) and organic C (2.31%). The results also showed that low total N (0.11%) and available phosphorous (14.69 mg kg^{-1}) whereas medium in extractable sulfur (19.7 mg kg^{-1}), boron (1.18 mg kg^{-1}) and CEC (23.16 cmol(+) kg^{-1}). The soil chemical properties after harvesting showed that application of blended fertilizers increased some chemical properties of soil such as total N, available sulfur and phosphorous after harvesting when compared with the composite sample taken before planting.

The analysis of variance revealed that the interaction effect of NPSB fertilizer with Rhizobium inoculation is significant on growth components such as plant height, number of primary and secondary branches per plant, number of nodule per plant, nodule fresh weight, nodule dry weight, nodule volume, effective nodule, shoot and root dry weight. This could be reason for integrated application of inorganic fertilizer (NPSB) with appropriate rhizobium strain (MB003) and varieties.

Moreover, a significantly increase in mung bean nodulation, yield, and yield component was observed as the rate increases. Number of effective nodule was influenced by interaction effect of rhizobium inoculation and fertilization. Similarly, interaction effect of fertilizer and rhizobium inoculation with different variety had significant effect on the growth, nodules, yield and yield related parameters. Thus, based on the present findings, it can be suggested that growing variety N-26 at NPSB rates100 kg ha^{-1}with Rhizobium inoculation can ensure better yield with the highest economic return for the farmers in the study area.

The variety N-26 showed superiority over NVL-1 by giving almost all growth and yield and yield parameters. The interaction effect of variety, rhizobium inoculation and rates of NPSB fertilizer revealed the highest net benefit (108,600.6 ETB) from N-26 variety at application of 100kg NPSB ha^{-1} with Rhizobium inoculation with the highest marginal rate of return (769.4%). The lowest (ETB 68,572.8 ha^{-1}) net return was recorded from the variety NVL-1 supplied with 0 kg NPSB ha^{-1} without seed inoculation. This shows economic feasibility of both treatments because the marginal rate of return from treatment with the highest net benefit is (769%) which is > 100%. So, 100kg NPSB ha^{-1} + Rhizobium inoculation could be considered as the most profitable treatment. Based on the results of this study, it can be concluded that mung bean varieties were highly varied in their agronomic performance mainly due to variation in their genetic background, response to rates of NPSB fertilizer and Rhizobium inoculate markedly affected agronomic performances of varieties.

5.1. Recommendation

The experiment was conducted at one site for one season and combined varieties, rates of NPSB fertilizer and Rhizobium inoculate were used, it was reasonable to point out that N-26 (Rassa) at application rate of 100 kg NPSB ha^{-1} with Rhizobium inoculate produced the highest seed yield of mung bean. The economic analysis has led to 100 kg NPSB ha^{-1} + inoculation with variety N-26 is suitable for potential adoption by farmers if additional study required to be undertaken on the same experiment to confirm for further use. However, similar studies should be conducted by including others mung bean varieties at different locations during different growing seasons and using different rhizobium inoculates with consideration of economic analysis in order to come to a conclusive recommendation.

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7. APPENDICES

Appendix Table 1. Mean square values of 50% DF 90% DM and PH, NBPP, NNPP, NFW ,NDW

		DF		DM		PH		PBPP		SBPP		NNPP		NFW		NDW	
Source	DF	MS	Pr>f	MS	Pr>f	MS	Pr>f	MS	Pr>f	MS	Pr>f	MS	Pr>f	MS	Pr>f	MS	Pr>f
REP	2	3.40	0.158	45.01	<0001	3.06	0.0902	0.004	0.8485	0.0133	0.5134	0.0	0.9913	0.03	0.3821	0.00004	0.8344
FERT.	3	59.25	<0001	229.88	<0001	68.69	<0001	0.925	<0001	1.2752	<.0001	153.3	<0001	4.60	<0001	0.09641	<0001
VAR.	1	70.08	<0001	25.52	<0001	38.52	<0001	0.608	<0001	0.7252	<.0001	176.3	<0001	3.52	<0001	0.05468	<0001
INOC.	1	96.33	<0001	90.75	<0001	196.02	<0001	0.480	<0001	0.0602	0.0895	265.1	<0001	5.33	<0001	0.16803	<0001
FERT*VAR	3	1.92	0.361	2.95	0.0268	0.97	0.4918	0.013	0.6706	0.0574	0.0492	32.3	<0001	0.79	<0001	0.00021	0.425
FERT*INOC	3	0.50	0.833	0.38	0.7211	5.35	0.0095	0.211	0.0002	0.2702	<.0001	7.2	<0001	0.26	0.0007	0.00412	<0001
VAR*INOC	1	12.00	0.013	1.02	0.2786	0.19	0.6922	0.141	0.0216	0.2852	0.0006	35.4	<0001	0.44	0.0012	0.03000	<0001
FERT*VAR*INOC	3	2.61	0.232	1.28	0.2265	0.74	0.5994	0.613	<.0001	0.1008	0.0054	10.3	<0001	0.04	0.0225	0.00022	0.3966
ERROR	30	23.72		19.19		16.17		0.32395833		0.713875		0.214		0.0342		0.00022	
Total	47																
CV (%)		7.95		5.66		9.82		12.9		11.5		6.31		12.26		9.24	

NB DF=date of flowering ,DM = date of maturity PH =plant height ,NNPP= number of nodule per plant ,NFW=nodule fresh weight and nodule dry weight

Appendix Table 2. Mean square values NV, EN, RFW, RDW NPPP and NSPP.

		NVOL		EN		SFW		SDW		RFW		RDW		NPPP		NSPP	
Source	**DF**	**MS**	**Pr>F**	**MS**	**Pr>f**	**MS**	**Pr>f**	**MS**	**Pr>f**	**MS**	**Pr.>f**	**MS**	**Pr>f**	**MS**	**Pr>F**	**MS**	**Pr>F**
Rep.	1	0.002	0.0423	0.06	0.8845	2.90	0.6296	0.121	0.0823	0.015	0.7461	0.0002	0.0467	7	0.0005	0.33	0.0439
FERT	3	2.196	<0001	95.44	<0001	210.72	<.0001	35.414	<0001	1.779	<.0001	0.0328	<.0001	534.97	<.0001	12.31	<.0001
VAR	1	1.505	<0001	95.44	<0001	108.00	0.0002	31.688	<0001	0.935	0.0002	0.0021	0.014	243	<.0001	8.33	<.0001
INOC	1	2.755	<0001	102.08	<0001	208.33	<.0001	36.053	<0001	4.142	<.0001	0.0494	<.0001	310.08	<.0001	18.75	<.0001
FERT*VAR	3	0.070	0.0004	225.33	<0001	8.06	0.2903	3.291	<0001	0.014	0.8436	0.0027	0.0003	0.889	0.3092	0.11	0.2064
FERT*INOC	3	0.121	<.0001	12.75	<0001	4.83	0.5121	2.536	<0001	0.284	0.0038	0.0030	0.0001	4.08	0.0031	0.31	0.0104
VAR*INOC	1	0.677	<.0001	6.56	<0001	1.33	0.6452	5.201	<0001	0.110	0.1536	0.0000	0.8716	21.33	<.0001	0.33	0.0351
FERT*VAR*INOC	3	0.037	0.0113	36.75	0.0004	0.83	0.0276	0.487	<0001	0.065	0.3067	0.0004	0.2698	3.22	0.0098	0.11	0.2045
ERROR	30	0.00854		0.507		6.163		0.044		0.0514		0.000313		0.185		0.1111	
Total	47																
CV (%)		8.55		12.95		6.98		2.45		7.53		3.29		14.35		7.93	

NB- NV= nodule volume ,EN =effective nodule ,RFW= root fresh weight RDW= root dry weight NPPP= number of pod per plant and NSPP= number of seed per plant

Appendix Table 3. Mean square values number seed per plant, HSW, grain yield, biomass and HI

		NSPP		HSW		GY		BM		HI	
Source	DF	MS	Pr>f	MS	Pr>F	MS	Pr>f	MS	Pr>F	MS	Pr>F
REP	2	1109.5	0.0062	0.394	<.0001	7943.33	<.0001	30625	0.0383	0.00001	0.8992
FERT	3	92432.6	<.0001	2.219	<.0001	914979.48	<.0001	2854097	<.0001	0.00412	<.0001
VAR	1	8775.0	<.0001	0.775	<.0001	152347.87	<.0001	67500	0.0081	0.0050	<.0001
INOC	1	50246.0	<.0001	3.050	<.0001	496458.72	<.0001	563333	<.0001	0.00935	<.0001
FRET*VAR	3	265.1	0.2498	0.027	0.0342	11704.09	<.0001	2500	0.8269	0.00054	0.018
FERT*INOC	3	1933.7	<.0001	0.107	<.0001	21323.23	<.0001	46111	0.004	0.00047	0.0283
VAR*INOC	1	1552.7	0.0068	0.035	0.0467	1226.14	0.1591	5208	0.4373	0.00010	0.3945
FERT*VAR*INOC	3	490.3	0.0654	0.032	0.0171	1892.90	0.0366	1875	0.8796	0.00009	0.5801
ERROR	30	0.989		0.998		8352.1		0.299		0.000136	
Total	47										
CV(%)		7.9		15.1		5.44		13.6		2.61	

. NB- HI= harvesting index ,HSW = hundred seed weight

Appendix Table 4 Mean square values soil lab result of PH, TN, av. P, ex S, and av B after harvesting

		PH		TN		avP		ex.S		avB	
Source	DF	MS	Pr>F	MS	Pr>f	MS	Pr>F	MS	Pr>f	MS	Pr>F
REP	2	0.000019	0.9975	0.0000019	0.5487	0.27	0.1066	0.05	0.8874602	0.00001	0.9962
FERT	3	0.015879	0.1246	0.00102225	<.0001	52.58	<.0001	117.20	2.20E-16	2.09531	<.0001
VAR	1	0.153002	0.0001	0.00016133	<.0001	42.73	<.0001	72.99	3.33E-14	0.15698	<.0001
INOC	1	0.055352	0.0116	0.00042008	<.0001	258.59	<.0001	0.19	0.4865249	0.8324	<.0001
FERT*VAR	3	0.041048	0.0045	0.00004272	<.0001	12.35	<.0001	11.67	4.89E-09	0.02049	0.0003
FERT*INOC	3	0.007406	0.4209	0.00001003	0.0359	23.31	<.0001	1.29	0.0332493	0.06177	<.0001
VAR*INOC	1	0.007008	0.3463	0.00009633	<.0001	31.12	<.0001	5.46	0.0007846	0.00845	0.0683
FERT*VAR*INOC	3	0.011529	0.233	0.00001817	0.0028	4.11	<.0001	1.47	0.0211705	0.01297	0.004
ERREOR	30	0.00765		0.0000031		0.111		0.39		0.00236	
	47										
CV (%)		1.31		1.04		2.25		3.26		4.82	

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Appendix Table 5.Ten year monthly temperature and precipitation through new loclim software

Month	Tem_[°C]_Min	Tem_[°C]_Max	Tem_[°C]_Mean	Precipitation[mm]
January	9.3	25	17.2	30
February	10.1	25.1	17.6	52
March	10.6	24.8	17.7	128
April	11.3	25.1	18.2	120
May	12.3	24.7	18.5	93
June	11.1	24	17.6	134
July	10.8	22.2	16.6	194
August	10.3	22	16.2	163
September	10.1	23.2	16.7	127
October	9.8	24	17	6
November	9.3	23.8	16.6	4
December	8.3	24.2	16.2	11
Mean	10.28	24.01	17.18	88.5

Tem=Temperature, oC=Degree centigrade, Min=Minimum, Max=Maximum mm=millimeter

Appendix Table 6 Interpretation (rating) of some chemical properties of soil

rating							
Parameter	Very low	low	Medium	high	Very high	Extraction Methods	References for rating
Total N (%)	-	< 0.05	0.05 - 0.12	0.12 - 0.25	> 0.25	Kjeldahl	Tekalign,1991
OC	-	< 0.5	0.5 – 1.5	1.5 – 3	> 3.0	Wet oxidation	Tekalign,1991
Available P(mg kg^{-1})	<9	10 – 17	18 – 25	26 – 35	>35	Bray	Jones, 2003
Extractable S(mg kg-1)	-	< 10	10 – 20	>20	-	Turbidimetric	Hariram and Dwivedi ,19
Boron (mg kg-1)	-	< 1.0	1.0 - 2.0	2.1 – 5.0	> 5	DTBA	Jones, 2003
CEC	< 5	5 – 15	15 -25	25-40	> 40	NH4Ac	Landon, 2013

Source: Atinafu ,T. (2020)

Appendix Table 7 Ranges of soil pH (for 1: 2.5 soil: water suspension

Soil reaction class	Extremely acidic	Very strongly acidic	Strongly acidic	Moderately medium acidic	Slightly acidic	Neutral	Slightly alkaline	Moderately alkaline	Strongly alkaline	Very strongly alkaline
Soil pH	< 4.5	4.5-5.0	5.1-5.5	5.6-6.0	6.1-6.5	6.6-7.3	7.4-7.8	7.9-8.4	8.5-9.0	> 9.1

Source: Jones, J. Benton (2003)