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FDRE TECHNICAL & VOCATIONAL TRAINING INSTITUTE

FACULTY OF AGRICULTURE AND AGRO-PROCESSING TECHNOLOGY

DEPARTMENT OF FRUIT AND VEGETABEL PROCESSING TECHNOLOGY

EFFECT OF NITROGEN AND PHOSPHOROUS RATES ON GROWTH, YIELD AND YIELD COMPONENTS OF MUNG BEAN (*Vigna radiata* L.) IN PAWE DISTRICT, METEKEL ZONE, NORTH WESTERN ETHIOPIA

MSc THESIS

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APRIL, 2026

ADDIS ABABA, ETHIOPIA

EFFECT OF NITROGEN AND PHOSPHOROUS RATES ON GROWTH, YIELD AND YIELD COMPONENTS OF MUNG BEAN (*Vigna radiata L.*) IN PAWE DISTRICT, METEKEL ZONE, NORTH WESTERN ETHIOPIA

A THESIS SUBMITTED TO TECHNICAL AND VOCATIONAL TRAINING INSTITUTE, FACULTY OF AGRICULTURE AND AGRO-PROCESSING TECHNOLOGY, DEPARTMENT OF FRUIT AND VEGETABEL PROCESSING TECHNOLOGY

IN PARTIAL FULFIIMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCEIN CROP PRODUCTION TECHNOLOGY

BY

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STATEMENT OF AUTHOR

First, I declare that this thesis is my original work and that all sources of material used for this thesis have been appropriately acknowledged. This thesis has been submitted in partial fulfillment of the requirements of M.Sc. degree at FDRE Technical and Vocational Training Institute, faculty of Agriculture and Agro-processing Technology and is deposited at the Institute library to be made available to users under rules of the Library. I seriously declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate. Brief references from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended reference from or reproduction of this manuscript in whole or in part may be granted by the head of the department or the Dean of the School of Graduate Studies when in his or her judgment the proposed use of the material is for scholarly interest. In all other instances, however, permission must be obtained from the author.

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BIOGRAPHICAL SKETCH

The author was born on Feb 12, 1992 G.C at Debati district, Metekel Zone, Benishangul Gumz Regional State to his father Lemessa Besizo and his mother Adisse Senbeta. He attended his elementary education at Berber Elementary School, and his secondary education at Berber Secondary School; and preparatory education, at Berber Preparatory School. Finally, he then joined in October 2011 Debra Markos University to pursue a study leading to the Degree of Bachelor of Biotechnology and graduated with BSc degree in July 2014.

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ABBERIVATIONS AND ACRONYMS

ANOVA	Analysis of Variance
AVRDC	Asian vegetarian Research and Development Centre
CEC	Cat Ion Exchange Capacity
CIMMYT	Centro International de Mejoreminto de Maizy Trigo
CSA	central statically agency
ECX's	Ethiopian commodity exchange
FAO	Food Association Organization
M.A.S.L	Meter above Sea Level
MARC	Melkassa Agricultural Research Center
MoA	Ministry of agriculture
MRR	Marginal Rate of Return
MSD	Minimum significance difference
PARC	Pawe Agricultural Research Center
RCBD	Randomized Complete Block Design
TUKEY HDS	Tukey Honestly significance difference

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Effect of Nitrogen and Phosphorous Rates on Growth, Yield and Yield Components of Mung Bean (*Vigna radiata* L.) in Pawe District, Metekel Zone, North Western Ethiopia

ABSTRACT

Mung bean is an important legume crops cultivated in Northwestern Ethiopia. However, its production and productivity is low due to lack of proper soil fertility management in the study area. Thus this experiment was conducted at the Pawe Agricultural Research Center in Northwestern Ethiopia during the 2025 cropping season to determine the optimal rates of nitrogen (N) and phosphorus (P_2O_5) to maximize mung bean productivity. The treatments consisted of factorial combinations of four N rates (0, 10, 20, and 30 kg/ ha) and five P_2O_5 rates (0, 23, 46, 69, and 92 kg/ ha). The experiment was laid out in Randomized Complete Block Design with three replications. The soil of the study area was strongly acidic (pH 5.4). Results showed that Days to flowering and physiological maturity were delayed by high Nitrogen rates but significantly shortened when Phosphorous was applied. The maximum plant height (57.77 cm), number of primary branches (9.07), and leaf area index (6.37) were achieved at the maximum treatment level of 30 kg N/ha and 92 kg P_2O_5/ ha. Besides, the maximum total number of nodules (43.0) and effective nodules (39.1) were achieved under the 0 kg N/ ha and 92 kg P_2O_5/ ha combination. The maximum grain yield (1755.7 kg/ ha) and aboveground biomass (5541.1 kg/ ha) were obtained with the application of 30 kg N/ ha and 92 kg P_2O_5/ ha, with three-fold yield increase over the control plots (552.2 kg/ ha). However, the highest Harvest index (34.37%) was obtained at a rate of 20 kg N ha^{-1} and 69 kg P_2O_5/ ha. According to the partial budget analysis, the highest net return (221,705 ETB/ha) with acceptable marginal rate return (238%) was obtained from 30 kg N/ha and 92 kg P_2O_5/ha. Thus the result of this study indicate that application of 30 kg N/ha and 92 kg P_2O_5/ha is increased mung bean productivity in the study area. However, further research across diverse agro ecological conditions and growing seasons is recommended to confirm these findings.

Keywords: *Grain yield, Nitrogen, Nodulation, Pawe, Phosphorous, Vigna radiata*

1. INTRODUCTION

1.1 Background

Mung bean (*Vigna radiata* L.) is a member of the legume family (Fabaceae). It has many local names "mung bean, mash, golden gram or green gram". It is an important short duration, self-pollinated diploid legume crop with high nutritive values and nitrogen fixing ability. It is an erect plant which is highly branched and is about 60 to 76 cm tall (Patil and Sarwar, 2024). It is one of the most important legume crops, grown from tropical up to subtropical areas around the world (Kebede & Bekeko, 2020).

The world annual production area of mung bean is around 5,500,000 ha with an increase in rate of 2.5% per annum (Bueno et al., 2020). In Ethiopia; Mung bean covers about 27,086 ha of land and produces 24,158.99 tons in rain fed per annum with average productivity of 0.9 t/ha (Ademe, 2023). Even though there are high potential, the productivity of Mung bean is low in Ethiopia as compared to the world average productivity of 1.2 t/ha, which is due to different factors such as lack of improved variety, disease, insect, inappropriate fertilizer application and poor agronomic practices (Birhanu et al., 2018). Mung bean is consumed in a the following forms, including seeds, sprouts, and immature pods, all of which are high in amino acids, vitamins, and minerals (Nair et al., 2013). The grain covers 24.2% protein, 1.3% fat and 60.4% carbohydrate (Ahmad et al., 2013). It has low calories and rich in fiber and easily digestible crop without causing flatulence as happens with many other legumes (Gehlot & Prajapat, 2021).

In Ethiopia, where starvation and food insecurity remain persistent challenges, legumes like Mung bean have great potential to support both nutritional and economic well-being (Shiferaw & Abewoy, 2023). The crop is characterized by fast growth and early matured under warm conditions, low water requirement and excellent soil fertility enhancement via nitrogen fixation (Belay et al., 2019). Even though this potential, the productivity of Mung bean remains below its potential due to several agronomic and environmental constraints, among which suboptimal soil fertility particularly deficiencies in nitrogen and phosphorus is a significant factor (Alene et al., 2021).

Nitrogen and phosphorus are amongst the utmost critical macronutrients required for best plant development. Nitrogen is vital for vegetative development and is a major component of

amino acids, proteins, nucleic acids, and chlorophyll. Phosphorus, on the other hand, is involved in energy transmission, root development, and reproductive processes, which straight influence seed development and yield (Demeke et al., 2020). While Mung bean, being a leguminous crop, can fix atmospheric nitrogen through symbiosis with Rhizobium bacteria, it still benefits from supplementary N, mostly during the initial growth stages before nodulation is fully functional (Gough et al., 2021). Also, phosphorus deficiency limits root development, nodulation, and ultimately the crop's ability to fix nitrogen efficiently (Alene et al., 2021).

The yield of Mung bean under nitrogen and phosphorus fertilization is hardly uniform; rather, it fluctuates based on a complex interplay amongst environmental variables, soil characteristics, and the specific genetic makeup of the variety. Through much of the tropics, including Ethiopia, agricultural soils are frequently exhausted of available N and P. This depletion is largely driven by continuous cropping rotations, soil erosion, and a chronic lack of organic matter replenishment. In the Pawe District of the Metekel Zone, for instance, the landscape is dominated by Nitisols soils that are inherently low in fertility and necessitate precise nutrient management to achieve better yields (Getaneh, 2022). While the region's warm, humid climate and uni-modal rainfall are theoretically ideal for Mung bean; local productivity is currently hindered because optimized agronomic practices, particularly balanced fertilization, remain underdeveloped (Shiferaw & Abewoy, 2023).

Current evidence has increasingly highlighted how balanced N and P applications can transform Mung bean growth and yield components. Demeke et al. (2020) verified that applying 23 kg N/ ha and 40 kg P /ha led to significant gains in primary branching, pod count, and seed weight under irrigation in Central Ethiopia. Also, in the Gewane area, Shiferaw and Abewoy (2023) found that a 30 kg P/ ha application, when paired with the Boreda variety, yielded the maximum net economic benefits. Such varied results underline the fact that nutrient responses are highly site-specific, making localized fertilizer recommendations a necessity somewhat a luxury.

Given that Mung bean is a vital pulse for both nutritional security and smallholder income, in addition considering the nutrient-poor status of soils in Pawe, there is a clear and urgent need for targeted study. Determining the optimal rates of N and P_2O_5 that maximize growth and yield under local conditions is essential. Addressing this gap not only empower farmers in the Metekel Zone but also sustenance Ethiopia's broader national objectives of boosting leg-

ume productivity and ensuring food security (Demeke et al., 2020; Alene et al., 2021). Therefore, the present study was initiated to evaluate how different levels of nitrogen and phosphorus influence the growth, yield, and yield-contributing traits of Mung bean in the Pawe District.

1.2 Statement of the Problem

In Ethiopia, the Mung bean has developed as a vital pulse crop, valued not only for its dense nutritional profile but also for its biological ability to replenish soil fertility through biological nitrogen fixation (Dikr, 2023). While the crop benefits from modest "starter" doses of nitrogen (roughly 10–40 kg N/ha) to boost shock early growth, excessive application can actually be counterproductive, suppressing the very nodulation and seed production it is meant to support (Kumar et al., 2018). Phosphorus is even further critical; Mung bean is extremely sensitive to P levels, which drive the development of roots and nodules. Depending on the baseline fertility of the soil recommended rates typically fall between 40 and 89 kg P_2O_5/ha (Kumar et al., 2018).

A growing body of evidence indicated that how a balanced approach to N and P_2O_5 fertilization can change growth outcomes. For example, Demeke et al. (2020) established that applying 23 kg N/ ha and 40 kg P/ ha in Central Ethiopia significantly boosted primary branching, pod counts, and 100-seed weight. The importance of phosphorus was further underscored by Singh and Pareek (2003), who observed that dry matter accumulation and seed yields peaked at a rate of 45 kg P_2O_5/ha. Economic viability is also a factor; Ravina et al. (2024) reported that phosphorus rates of 46 kg P_2O_5/ ha yielded marginal rates of return (MRR) well above the 100% threshold.

In Benishangul Gumze Region the productivity of Mung bean averagely about 10 -11 Q/ha and in Metekel zone about average of 9-10 Q/ha Moreover less in the Pawe district is 6.0 – 8.5 Qt/ha (Dikr. 2023). However the productivity of mung bean in the study area is roughly 25–35% lower than the national average (approx. 11 Qt/ha) and often 40–50% lower than the global average (12 Qt/ha).

Mung bean production in the Metekel zone's Pawe district is still low and erratic despite its potential due to the absence of region-specific nutrient management techniques, especially with regard to the application of nitrogen and phosphorus, which are crucial macronutrients for plant growth and development, is one of the main challenges in Mung bean production in the study area.

Currently, suboptimal yields result from farmers in the study area applying fertilizers either insufficiently or without the necessary guidance. Furthermore, the proper rates and combinations of N and P_2O_5 for mung bean cultivation in the study area are not well supported by research. The region's attempts to maximize production and use mung beans as a sustainable crop for soil improvement and food security are hampered by this knowledge gap.

Therefore, there is an urgent need to investigate the effect of nitrogen and phosphorus rate on the growth, yield, and yield components of mung bean under the agro-climatic conditions of the study area. Such information will not only benefit farmers in the study area but could also contribute to broader national goals of improving legume productivity and ensuring food security (Demeke et al., 2020; Alene et al., 2021). Thus this study was designed to evaluate the effects of different levels of nitrogen and phosphorus on the growth, yield, and yield components of Mung bean in the Pawe District.

1.3 Objectives

1.3.1 General Objective

- To increase the production and productivity of mung bean through determining optimal nitrogen and phosphorus fertilizer rate in Pawe district, Benishangul Gumze.

1.3.2 Specific Objectives

- To evaluate the effects of Nitrogen and Phosphorus fertilizer rates on growth, yield and yield components of Mung bean
- To determine economically optimal Nitrogen and Phosphorus fertilizer rates to maximize Mung bean productivity in Pawe district

2. LETRIETURE REVIEW

2.1 Origin, Distribution and Botany of Mung Bean

The center of origin, genetic diversity including wild relatives, domesticated and cultivated Mungbean (*Vigna radiata* (L) Wilczek) with the family *Fabaceae*; is Asia specifically India Burma region in Neolithic sites of southern India (Fikadu Tekle & Sharma, 2017). The findings also views to both south-eastern and western Himalayan foothills as likely places where domestication could have been taken place (Fuller, 2011). The primary genetic diversity and center of origin for the crop was the central Asian region with India having the widest diversity of domesticated varieties, and wild relatives (Kidanie, 2022). It is currently grown widely in Southeast Asia, Africa, South America, and Australia, also it is regarded as a high-yielding pulse crop (Ayalew , 2019). Mung bean agriculture has grown all over the world due to the short time it takes to grow and its extensive adaptability, as well as the ease with which it may be digested (Kidanie, 2022). Mung bean is an annual crop 65-120 days to harvest; that grows to be 0.3 to 1.5 meters tall, erect or sub-erect, and often twines at the tips (Kidanie, 2022). It has a deep and tap root system and it is also heavily branched, with long petioles (Kidanie, 2022). The leaflets are oval and range in size from 5 to 12 cm wide and 2 to 10 cm long(Chen & Nelson, 2004). The leaves are alternating, trifoliate, and dark or light green. An axillary raceme with a peduncle 2 to 13 cm long, the inflorescence is an axillary raceme (Rahman et al., 2020). The keel petal is spirally coiled with a horn-like appendage, and the bloom is yellow (Ayalew Kebede, 2019). Pods range in length from 6 to 10 cm and are slender, short, and hairy. Seeds are globes, 15 to 85 mg in weight, typically green but occasionally yellow, tawny brown, black, or mottled, and epigeal germination (Arain, 2012).It is a very early maturing crop with unique characteristics such as high yield, good nutritional value, earliness and drought resistance, low production costs, and the ability to induce Striga without being parasitized (Dikr, 2023). The germination of Mungbean is epigeal with the cotyledons and stem emerging from the seedbed (Fikadu & Sharma, 2017).

2.2 Agro-climatic Requirements of Mung Bean

Mung bean is widely distributed in the tropics and subtropics. It's known as a 'short day' plant (Lawn & Cottrell, 1988). The sensitivity of cultivars varies greatly, although most genotypes exhibit quantifiable short-day responses, with flower initiation being delayed as the photoperiod lengthens (Carberry et al., 2001). While qualitative responses (no flower initiation if photoperiod exceeds a crucial value) have been seen, absolute day neutrality has yet to be established (Kidanie, 2022;(Ayalew Kebede, 2019). It is a warm-season annual grain legume with an ideal temperature range of 27-30 °C for good production (Tsegaye et al., 2019;(Asfaw et al., 2012), hence it is typically grown in the summer. When the minimum temperature is above 15 °C, seed can be planted. Until ensure a decent harvest, enough rainfall is required from flowering to late pod fullness. It thrives in fertile, sandy loam soils with excellent internal drainage and a pH of 6.3 to 7.2 (Kidanie, 2022).

2.3 Production and Importance of Mung Bean

Mung bean is an important cash crops serve as a source of income and foreign currency in the world (Tegegne, 2017). In developing countries, Mung bean is consumed as dry seeds, fresh green pods, or leaves and seeds as vegetables due to its high protein, vitamin, and mineral content (Demeke, 2017). The main objective of producing Mung bean is for its protein-rich edible seeds and fresh sprout; mainly used for making soups, bread, and biscuits (Demeke, 2017). In addition to food, it has the capacity to fix atmospheric nitrogen which rehabilitates the soil fertility status, use of land and water resources (Kumar et al., 2023). Mung bean is one of the most important grain legumes for generating money (Kidanie, 2022). Its demand is expanding rapidly in the global import-export industry (Kidanie, 2022). It was just added to ECX's list of exported commodities in Ethiopia (Ibrahim, 2020). It can also be prepared as cooked fresh or dry. They can be eaten whole or made into flour, soups, porridge, snacks, bread, noodles and ice-cream. Split seeds can be transformed into dhal in the same way as chickpea or lentils.

Mung bean production is largely concentrated in Asia, where about 90% of the world's supply is grown (source). India leads the charge, accounting for more than half of global production and consuming nearly all of it domestically. China follows closely behind, with mung

beans making up 19% of its total legume output (source). Thailand, meanwhile, has emerged as the main exporter of mung beans, with production growing at an impressive rate of 22% annually from 1980 to 2000, as reported by Harouna et al. in 2018. In Africa, although mung beans are grown in several countries, they haven't yet become a major crop there, and productivity remains low (Kidanie, 2022). In the United States, mung beans are primarily known for their use in making bean sprouts. The Asian Vegetable Research and Development Centre (AVRDC) in Shantua Tainan, Taiwan, has even designated mung beans as one of their priority crops (AVRDC, Akpapunam, 1996). Australia is another significant producer, with mung beans grown from the Northern Territory down to southern New South Wales (Pasley., et al 2024). Most of this Australian crop comes from central and southern Queensland and northern New South Wales, and the majority is exported to countries like Taiwan, the Philippines, the United States, and the United Kingdom (Rusak., 20212). Mung beans are especially popular in Southeast Asian cuisine, featuring prominently in the dishes of China, Thailand, Japan, Korea, Vietnam, and India (McMahon, 1999).

Mung bean is grown in Ethiopia's lower, dryer, and warmer regions (Kidanie, 2022). It was made in Shewa, Hararge, Ilubabor, Gamogofa, Tigray, and Gondar, among other places (Keatinge et al., 2011). Its production is gaining popularity among farmers, and Ethiopia's mung bean exports have increased marginally year after year. Mung bean is a grain legume grown by small holder farmers in drier marginal environments, and it has been an essential grain legume for resource poor farmers in these areas, despite its low productivity in Ethiopia when compared to other pulse crops (MOARD, 2008; Itefa, 2016).

2.4 Historical Perspective and Overview of Mung Bean Production in Ethiopia

In Ethiopia; Mung bean covers about 27,086 ha of land and produces 24,158.99 tons in rain fed per annum with average productivity of 0.9 t/ha (Ademe, 2023). Even though there are high potential, the productivity of Mung bean is low in Ethiopia as compared to the world average productivity of 1.2 t/ha, which is due to different factors such as lack of improved variety, disease, insect, inappropriate fertilizer application and poor agronomic practices (Birhanu et al., 2018). So, farmers regard mung bean as a traditional crop.

Currently, mung bean is mainly cultivated in North Shewa, Oromiya Special Zone, Southern Wollo, Harerge, Illubabor, Gamo Gofa, Tigray, and Gondar (Keatinge et al., 2011; Kidanie, 2022). In Southern Ethiopia, farmers were living in pocket areas that are vulnerable to moisture stress, scanty and erratic rainfall distribution (Gofa, Konso, South Omo Zone, and Konta) produce it to supplement their nutritional needs (Asfaw et al., 2012). Amhara and Benishangul Gumuz regions are the two potential production areas of green Mung bean In Ethiopia, the green grams do well in the lowland areas. This is because they require 6-8 hours of sunlight per day, and thrive in well-drained areas hence loam-sandy soils and a pH of 6-7 (Dikr2023).

Even though the international market demands for mung bean is increasing, there is a demand-supply gap in Ethiopia from the production side even if export has grown slightly from time to time (Kidanie, 2022).

2.5 Production Constraints of Mung bean

Productivity of mung bean is decreased through biotic and a biotic stresses including diseases, insect pests, drought stress, water stress, extreme high temperature, salinity stress as well as heavy metals (Das et al., 2020). Salinity stress is a serious problem in arid and semi-arid tropics and in the plains in irrigated areas. Due to global climate change, mung bean also encounters the cumulative adverse effects of other environmental factors such as insects, pests, high temperature, and pod shattering along with salinity causing high yield loss (Kidanie, 2022). Yield is unstable over locations and seasons due to the susceptibility of mung bean cultivars to environmental stress and disease. This has led to mung bean being grown on marginal lands with a minimum management inputs. Natural selection under such situations has favored types that can survive under unfavorable environments and culture. Although resistance to certain diseases are present in varying degrees in some cultivars, diseases like powdery mildew and leaf spot are still major risks in growing mung bean in some production areas and also, mung bean yellow mosaic virus is a serious threat for mung bean production in certain seasons in the Indian subcontinent. In countries where labor is becoming expensive, there is no synchronous pod maturity that necessitates multiple harvesting by hand is yet another problem because of shattering (Poehlman, 1991).

According to Das et al. (2020), the productivity of Mung bean is decreased through biotic factors such as diseases and insect pests and abiotic factors which include drought stress, water stress, extremely high temperature, salinity stress as well as heavy metals. Drought tolerance at the reproductive stage is the most important in terms of economic yield. Nitrogen fixation in crop species is sensitive to environment constrains especially for drought (Ranawake et al., 2012) Water stress also affects crop phenology, leaf area development, number of leaves per plant and finally results in low yield. Number of leaves per plant is directly related with leaf area/plant and with final dry matter weight of shoots (Arrese et al. 2009).

The proper method of planting in a given area of land is an important biotic factor that determines the proper plant population or density in space provided, which improves the performance and productivity of plants in the field. Plant population plays an important role as it is one of the most important yields affecting and contributing characters (Rafiei, 2009). There are also many challenges in Mung bean production: unpredictable rainfall, prevalence of pests and diseases, lack of input supply and development, lack of proper storage and handling and low levels of local consumption (Mohamed et al., 2015). Ethiopia, according to Tensay (2015) abiotic factors limiting yields of Mung bean in terms of both quality and quantity are extreme drought, cold weather, untimely rain (rain after pod filling) and type of soil used for cultivating it. Biotic factors limiting Mung bean productivity includes weeds, leave diseases, flying insects on pod and leave at any growth stage (Tensay, 2015). Chadha (2010) reported that all parts of crop plant including root, stem, branches, petiole, leaves, pods and seeds of the crops are vulnerable to disease and pest.

2.6. Effect of Soil Fertility on Mung bean

Soil fertility really shapes how mung beans grow and how much they yield, especially when it comes to the essential nutrients like nitrogen and phosphorus. Sure, mung beans can fix their own nitrogen since they're legumes, but they still need an initial supply of starter nitrogen and plenty of phosphorus to encourage strong roots and good nodulation. Researchers have noticed that when you combine inorganic fertilizers with organic materials, plants grow taller, bigger leaves, and more dry matter compared to leaving the soil untreated. Phosphorus stands out here. It’s key for energy transfer and metabolism. If the soil lacks phosphorus, the plants just don’t grow well they stay small and require a very long time to mature. With

enough phosphorus, though, more pods develop on each plant and better seed yields (Aslam et al., 2019).

Micronutrients and bio fertilizers matter a lot, too, especially if you care about sustainability. Bio fertilizers like Rhizobium or phosphate-solubilizing bacteria actually improve soil health they make nutrients easier for the plants to absorb. When farmers use integrated nutrient management and add micronutrients like zinc and boron to the usual NPK fertilizers, there is an increase in seed protein and grain quality gets better (Hossain et al., 2020). All of this indicated that depending merely on the soil's existing nutrient supply is not sufficient for optimal yields. Stable fertilization is vital to replace lost nutrients and satisfy the crop's needs, mainly during the reproductive stage.

2.7. Effect of Nitrogen on Phenology, growth Yield and Yield Components of Mung Bean

Nitrogen fertilizer makes a significant impact on mung bean (*Vigna radiata L.*) growth and yield. When nitrogen is increased, plants grow taller they produce more branches, leaves become broader, and the leaf area index rises. This is mainly due to an increase in chlorophyll, which helps the plant carry out photosynthesis more efficiently (Sahu et al., 2021; Kumar et al., 2022). Nitrogen speed up growth; it also extends the vegetative stage and delays maturity a bit. This longer period allows the plant to accumulate more biomass. When nitrogen is applied at the optimal rate, the results at harvest are clear: there are more pods per plant, more seeds in each pod, and heavier seed weights. Altogether, these improvements lead to a substantial increase in grain yield (Hossain et al., 2021; Choudhary et al., 2023).

2.7.1. Effect of Nitrogen on Phenology and Growth of Mung Bean

The application of nitrogen fertilizer plays a significant role in the growth trajectory of Mung bean, however its effects are highly dose-dependent. At the earliest stages, the right amount of nitrogen acts as a catalyst; for instance, Rahman et al. (2022) found that a starter dose of 25 kg N/ha at sowing improved germination by 12% and enhanced seedling vigor by up to 25%. However, there is a clear threshold for this benefit. Both Kumar et al. (2020) and Ahmed et al. (2023) cautioned that exceeding 50 kg N/ha can actually delay germination by 5 to 7 days, likely due to osmotic stress.

Sefera et al. (2021) and Woubshet et al. (2017) found that when seedlings emerge typically depends on the nutrients stored inside the seed and on environmental factors like moisture and temperature, rather than soil fertility at this stage. This means that changing soil nitrogen doesn't significantly affect how fast seedlings emerge. Achakzai and Habibullah (2012) observed that flowering took the longest about 48 days when the highest nitrogen rate of 100 kg per hectare was applied, whereas lower nitrogen levels led to earlier flowering. Sefera et al. (2021) confirmed that with 200 kg/ha of NPS fertilizer, it took roughly 49 days for half the plants to flower. High nitrogen encourages more leaf and stem growth, which delays flowering. Sefera et al. (2021) showed the Rasa variety needed over 81 days to reach 90% maturity with 150 kg/ha NPS, compared to just 68 days for the control. This delay is due to nitrogen maintaining higher chlorophyll and ongoing photosynthesis, creating a "stay green" effect that delays maturity.

Achakzai and Habibullah (2012) observed that plants reached a height of 38.52 cm when 100 kg N/ha was applied. They also reported that at this same nitrogen level, each plant developed about 3.83 primary branches, indicating that nitrogen had a noticeable impact. This finding is supported by Kabir et al. (2019), who demonstrated that sufficient nitrogen led to more primary branches because it provides the energy needed for new bud growth. Similarly, Sefera et al. (2021) recorded 3.11 branches per plant at 200 kg/ha NPS and noted that nitrogen contributes to stronger plant structure. Mondal et al. (2020) found the highest leaf area index (LAI) at the flowering stage when 40 kg ha^{-1} of nitrogen was applied, which was 25% greater than in plants that received no fertilizer. This increased leaf area is important, as it enables the plant to capture more sunlight, accumulate more biomass, and achieve better pod filling later on.

As the crop moves into its vegetative phase, moderate nitrogen levels (30–40 kg N/ha) are essential for driving leaf expansion and stem elongation. Studies by Patel et al. (2021) and Das et al. (2020) indicate that this range produces plants that are roughly 20% taller and possess a significantly higher leaf area index compared to unfertilized controls. These physiological gains are mirrored by chlorophyll levels; Yadav et al. (2020) and Sharma et al. (2021) observed that SPAD meter readings and LAI values peak at approximately 40–50 kg N/ha.
Conversely, excessive fertilization often yields diminishing returns. When nitrogen levels surpass 60–70 kg N/ha, the plant shifts toward "luxurious" vegetative growth While, this may

result in even taller plants, Ghimire et al. (2022) and Biswas et al. (2021) warned that it leads to weaker stems and a higher risk of lodging. Furthermore, this overgrowth often comes at the expense of the harvest index, which can drop by up to 20% as the plant prioritizes foliage over seed production (Patra et al., 2022).

The timing of reproductive milestones is also sensitive to nutrient availability. Optimal nitrogen (30–50 kg N/ha) can advance flowering by 5 to 10 days and increase the total flower count per plant (Singh & Prasad, 2022). While some waterlogged conditions may obscure these differences (Amin et al., 2015), the general consensus suggests that moderate N levels optimize the transition from growth to reproduction. Similarly, pod development including length and count is maximized at moderate rates, typically peaking around 45 kg N/ha before declining (Asian et al., 2015; Eman et al., 2014).

2.7.2. Effect of Nitrogen on Nodulation of Mung Bean

Mung bean (*Vigna radiata*) is a vital legume distinguished by its symbiotic partnership with nitrogen-fixing bacteria, such as *Bradyrhizobium* and *Rhizobium* spp. This biological nitrogen fixation (BNF) is a natural mechanism that can significantly offset the need for synthetic fertilizers. However, the introduction of external nitrogen creates a complex physiological trade-off: while small amounts can jumpstart the plant, excessive levels often stifle its natural ability to fix nitrogen.

Research consistently suggests that a "starter" dose of nitrogen is beneficial for early establishment without compromising the plant's symbiotic potential. For example, Kebede (2021) and Rahman et al. (2020) both observed that applying 20–25 kg N/ha at the time of sowing enhances seedling vigor and nitrogenase activity. In these modest amounts, the nitrogen supports the plant during its "hunger period" before the nodules have fully matured to take over the role of nutrient supply. As fertilization rates increase, the plant begins to prioritize soil-based nitrogen over biological fixation, leading to a decline in nodule health. Singh et al. (2019) and Dutta et al. (2021) noted that while 40–50 kg N/ha may maintain a balance in biomass, pushing the rate to 60 kg N/ha can trigger a 15–20% reduction in nodule formation and dry weight. This inhibitory effect becomes even more pronounced at higher levels. Ahmed et al. (2022) demonstrated that application rates of 80 kg N/ha can slash nodule counts by 40% and nearly halve nodule fresh and dry weights compared to more moderate regimes.

The reason for this decline is rooted in the chemical signaling between the plant and the bacteria. High concentrations of nitrate (NO_3^-) or ammonium (NH_4^+) have been shown to inhibit the expression of *nod* genes and reduce the secretion of flavonoids required for bacterial signaling (Ferguson et al., 2020). Beyond preventing new nodules from forming, high nitrogen levels also cause feedback inhibition in existing nodules, restricting the carbon allocation they need to grow. These results in smaller, non-functional nodules that fail to reach metabolic maturity (Herridge et al., 2021).

Evidence suggests that the most sustainable path to high yields is not through high-input chemistry, but through integrated biological management. Patil et al. (2020) found that inoculated mung beans achieved peak nodulation with only 20 kg N/ha, whereas uninoculated plants required significantly higher rates to reach comparable yields. This highlights a clear advantage in combining low-dose nitrogen with rhizobial inoculation.

Furthermore, recent studies by Tadewos et al. (2022) emphasize the importance of organic amendments. Their analysis showed that integrating bio-slurry with a modest 23 kg N/ha and specific rhizobial strains (like MB-001) significantly improved nodule numbers and biomass. By utilizing these integrated practices, farmers can optimize the growth and maturation of mung beans while maintaining the ecological benefits of biological nitrogen fixation.

2.7.3. Effect of Nitrogen on Yield and Yield Components of Mung Bean

Nitrogen (N) fertilization is a primary determinant of mung bean productivity, influencing everything from pod development to final grain weight. Research generally suggests that the relationship between nitrogen and yield follows a quadratic trajectory: productivity climbs as nitrogen is added, peaks at a specific threshold usually between 30 and 50 kg N/ha and then begins to plateau or decline (Meena et al., 2021; Singh & Prasad, 2022).

The number of pods per plant is perhaps the most sensitive indicator of nitrogen availability. While unfertilized controls often struggle to produce more than 12–15 pods, moderate applications (40 kg N/ha) can boost this to 18–22 pods (Patel et al., 2021). This trend is supported by various regional studies; for instance, Mezgebu et al. (2020) and Fazil et al. (2024) found that even lower doses (20–23 kg N/ha) significantly improved pod counts and branching. However, there is a physical limit to this benefit. When nitrogen exceeds 60–80 kg N/ha, the

plant may produce more flowers, but increased flower abortion and pod shedding often negate any potential yield gains (Kumar et al., 2022; Rahman et al., 2023). Pods per plant and seeds per pod are key factors in yield, and each responds differently to nitrogen. Razzaque,. et al (2015) observed a clear pattern: increasing nitrogen leads to more pods. Without any nitrogen (0 kg N/ha), plants produced about 12.5 pods each. At 40 kg N/ha, pod numbers rose to 16.33, and with 60 kg N/ha, they reached 18.05 pods per plant. This happens because nitrogen slows leaf aging and encourages flower development, allowing plants to keep producing pods for a longer period. Seeds per pod follow a similar trend. Achakzai et al. (2012) found that plants grown without extra nitrogen averaged only 8 seeds per pod, but applying 50 kg N/ha increased that to 10.5. Additional nitrogen supports seed development, reducing seed loss as pods mature.

Interestingly, the number of seeds within each pod appears to be governed more by genetics than by nutrition. While severe nitrogen deficiency can lead to stunted pods with only 6–7 seeds, most researchers observe a stable average of 10–12 seeds across a wide range of fertilization levels (Das et al., 2022; Ghimire et al., 2023). Nitrogen also plays a vital role during the seed-filling stage. Moderate doses (around 40 kg N/ha) improve photosynthetic activity, ensuring that more assimilates are partitioned into the developing seeds. This typically raises the 1000-seed weight from roughly 35g to over 40g (Yadav et al., 2021; Sharma et al., 2023). Applying nitrogen fertilizer enhances the source-sink relationship during grain filling, resulting in heavier and more filled seeds. This impact is clearly seen in the 1000-seed weight. Sadeghipour et al. (2010) observed this in their study. Plants grown without nitrogen produced seeds with a 1000-seed weight of only 43.5 grams. With the addition of 60 kg of nitrogen per hectare, the weight increased to 48.2 grams. The heaviest seeds were recorded at 90 kg N/ha, reaching 51.8 grams. These findings demonstrate that supplying more nitrogen helps the plant transfer photosynthates more efficiently to developing seeds. While pushing nitrogen levels higher (to 60 kg N/ha) might slightly increase seed weight further, the economic returns often vanish as the harvest index drops and fertilizer costs climb (Biswas et al., 2022). on a macro level, grain yield exhibits the most dramatic response to nitrogen.

When plant height, number of pods, and seed weight all increase together, total grain yield per hectare rises significantly. Sadeghipour and colleagues (2010) reported that control plots without nitrogen (0 kg N/ha) yielded about 1,683 kg/ha (168.3 g/m²). Increasing nitrogen to 60 kg N/ha raised yields to 2,112 kg/ha. The highest yield was observed at 90 kg N/ha, reach-

ing 2,242 kg/ha a notable 33% increase over the control. Similarly, Oad and Buriro (2005) found their unfertilized plots produced 1,050 kg/ha, but with 70 kg N/ha, yields peaked at 1,295 kg/ha. These findings clearly show that managing nitrogen is crucial for maximizing Mung bean crop yields. Field experiments consistently show a leap from 800 kg/ha in control plots to roughly 1300 kg/ha with optimized fertilization (Mondal et al., 2023). However, the "law of diminishing returns" is clearly evident here. Beyond 50–60 kg N/ha, the yield response flattens. Excessive nitrogen (80–100 kg N/ha) can even backfire, triggering luxury vegetative growth, causing the crop to lodge, and increasing its vulnerability to pests (Ahmed et al., 2023; Razzaque et al., 2017).

Optimal rates are not universal and often depend on environmental stressors and soil history. For example, in flooded or paddy-fallow conditions, researchers have found that much lower rates between 12.5 and 25 kg N/ha are sufficient for maximum efficiency (Amin et al., 2015; Rudreshhappa & Halikatti, 2002). Conversely, under intensive summer cultivation or specific genotype requirements (like BARI mung-6), researchers such as Mosarref et al. (2015) and Salam et al. (2020) have argued for higher rates of 45–60 kg N/ha to reach peak biological yield.

2.8. Effect of Phosphorous on Phenology, Growth Yield and Yield Components of Mung Bean

Managing phosphorus the most important for Mung bean (*Vigna radiata* L.) it's a game changer. Phosphorus drives key metabolic processes that shape the crop's phenology, root system, and final yield. Unlike nitrogen, phosphorus really shines when it comes to root development and nodulation. Stronger root proliferation and more efficient nodules, means better biological nitrogen fixation. That translates into a healthier canopy, taller plants, and more branches (Singh et al., 2021). During the reproductive stage, phosphorus acts like fuel. It speeds up flowering and pod setting and shortens the time from flowering to maturity. Field data backs this up: when you boost phosphorus, you see more pods per plant, higher seeds per pod, and increased 100-seed weight. Phosphorus improves assimilate partitioning, pushing more photosynthates from source leaves to developing pods. In the end, it gives bigger yields and better grain quality (Solanki et al., 2022; Kumawat et al., 2023).

2.8.1. Effect of Phosphorus on Phenology and Growth of Mung Bean

Phosphorus (P) serves as the primary energy currency for mung bean development, driving physiological processes from the moment of imbibition to final crop maturity. At the metabolic level, phosphorus accelerates early growth by enhancing ATP synthesis. Research indicates that evens a modest application of 20 kg P_2O_5/ha can shorten the germination window by up to three days (Kumar et al., 2021). This early momentum translates into superior seedling vigor; studies show that seedlings provided with 30–40 kg P_2O_5/ha develop more leaves and robust shoot lengths within the first two weeks of growth compared to those in phosphorus-deficient soils (Patel et al., 2023; Rahman et al., 2022).

As the crop moves into its vegetative phase, phosphorus availability becomes the main architect of the plant's physical structure. Optimal P levels generally cited between 35 and 45 kg P_2O_5/ha significantly boost leaf production, stem diameter, and overall plant height (Meena et al., 2023; Das et al., 2022). These structural improvements are not merely aesthetic; thicker stems (up to 1.0 mm wider) provide vital resistance against lodging, while increased leaf area drives the photosynthetic capacity needed for biomass accumulation (Ghimire et al., 2023).
Below the surface, the impact is even more pronounced. Adequate phosphorus (30 kg P_2O_5/ha) can expand the lateral root network by 40% and increase rooting depth by 5–8 cm (Dutta et al., 2023). This subterranean expansion allows the plant to access deeper water reserves and nutrients, effectively lowering the root-to-shoot ratio as the plant prioritizes above-ground reproductive growth (Ferguson et al., 2023).

One of the most critical roles of phosphorus is its ability to regulate the plant's internal clock. By providing the energy required for floral induction, P applications of 25–35 kg P_2O_5/ha can advance flowering by nearly a week (Yadav et al., 2022). This acceleration is often paired with an extended flowering duration, which widens the window for successful pollination (Sharma et al., 2023). Conversely, phosphorus deficiency tends to trap the plant in a prolonged vegetative state, shortening the reproductive phase and ultimately curbing yield potential (Biswas et al., 2023). Samim et al. (2023) reported that applying 60 kg P_2O_5 ha^{-1} resulted in the maximum plant height of 63.50 cm, compared to lower values in control plots. Similarly, Patel et al. (2022) observed that plants treated with 60 kg P ha^{-1} were significantly taller (70.0 cm) than control plants (64.4 cm).

While the literature offers a range of "ideal" doses, a clear consensus emerges around the 40–60 kg P_2O_5/ha window. Extensive field trials across various genotypes such as Boreda, Rasa, and Watani consistently show that this range maximizes plant height, branching, and dry matter accumulation (Khalilullah et al., 2023; Eyaya & Damtew, 2023; Suman et al., 2021). For instance, Boreda reached maturity nearly 10 days faster when supplied with 40 kg P_2O_5/ha compared to low-input treatments (Eyaya & Damtew, 2023).

Interestingly, while some growth parameters reach a plateau, others like fruit-bearing branches and pod length continue to show sensitivity to phosphorus levels up to 60 or 65 kg/ha , particularly when combined with Rhizobium or PSB inoculation (Ubey et al., 2018; Dhewa et al., 2017).

2.8.2. Effect of Phosphorus on Nodulation of Mung Bean

Phosphorus is an indispensable catalyst for biological nitrogen fixation in Mung beans, primarily because the formation and maintenance of root nodules are energy-intensive processes. Research consistently indicates that phosphorus availability directly dictates the quantity, quality, and spatial distribution of these nitrogen-fixing structures.

The relationship between phosphorus application and nodule count follows a clear optimization curve. Phosphorus-deficient soils severely limit symbiotic activity applying between 30 and 40 kg P_2O_5/ha have been shown to boost nodule numbers significantly, often resulting in 25–30 nodules per plant (Singh et al., 2023; Meena et al., 2022).The benefits of phosphorus are most visible in the upper root zone (0–15 cm), where P-fertilized plants develop significantly more nodules compared to unfertilized controls (Islam et al., 2023). However, there is a biological ceiling; pushing application rates beyond 50–60 kg P_2O_5/ha typically yields diminishing returns, as excessive P can alter root-shoot partitioning and stall further nodule proliferation (Ghimire et al., 2023).

Beyond simple counts, phosphorus is critical for the "effectiveness" of the symbiosis. Functional nodules are identified by their pinkish color a sign of leghemoglobin synthesis and phosphorus availability has been linked to a 15–20% increase in the proportion of these effective nodules (Dutta et al., 2023; Yadav et al., 2023). From an anatomical perspective, adequate phosphorus (around 35 kg P_2O_5/ha) allows nodules to develop larger active zones pop-

ulated with nitrogen-fixing bacteroids (Ferguson et al., 2023). This structural improvement manifests as higher nodule biomass, with both fresh and dry weights peaking under optimized P regimes (Patra et al., 2023; Biswas et al., 2023).

Phosphorus also regulates the timing of the symbiotic relationship. Fertilized plants tend to initiate nodulation 2–3 days earlier and maintain active nodules roughly a week longer than their P-deficient counterparts (Singh & Prasad, 2023; Sharma et al., 2023). This extended window of activity is vital for maximizing nitrogen intake during the plant's peak growth phases. However, the magnitude of this response is heavily influenced by the soil's native phosphorus levels. In P-poor soils, the impact of fertilization is dramatic, whereas in medium-fertility soils, the response is more modest (Ahmed et al., 2023; Sophoanrith et al., 2022).

2.8.3. Effect of Phosphorus on Yield and Yield Components of Mung Bean

The yield potential of mung bean is fundamentally anchored to phosphorus (P) availability, which dictates the efficiency of several key physiological drivers. Empirical evidence suggests that even a modest application of 25 kg P_2O_5/ha can significantly boost pod counts (Tiwari et al., 2022). For many researchers, the "biological sweet spot" for pod production lies between 30 and 46 kg P_2O_5/ha, where plants consistently produce between 22 and 28 pods (Choudhary & Patel, 2023; Getachew et al., 2020; Eyaya & Damtew, 2023).

This nutritional influence extends down to the individual pod level. Balanced phosphorus application typically around 30–40 kg P_2O_5/ha improves ovule fertilization and reduces seed abortion, resulting in a stable increase from 9 to 11 seeds per pod (Malik et al., 2023; Singh et al., 2015). While extreme applications (up to 85 kg P/ha) have been reported to maximize seed counts in specific trials (Nusrat et al., 2020), most cultivars show a fundamental physiological limit at more moderate levels (Arora & Singh, 2023). Similarly, seed bulk improves with P-fertilization; 1000-seed weight typically rises from 38g in unfertilized plots to over 45g when supplied with 30–40 kg P_2O_5/ha, driven by more efficient carbohydrate metabolism during the seed-filling phase (Verma et al., 2023; Fazil et al., 2024; Mezgebu et al., 2020).

Samim et al. (2023) observed that plants produced 18.33 pods per plant when supplied with 60 kg P_2O_5 ha^{-1}, whereas the control group without phosphorus produced only 13.75 pods per

plant. Ahmad et al. (2018) reported even higher numbers: at the same phosphorus rate, plants reached 22 pods per plant, while the control group had just 16. Gezu Degefa et al. (2021) also found that applying phosphorus significantly increased pod count, highlighting that row spacing and phosphorus interacted to affect the results. Samim et al. (2023) found that the number of seeds per pod rose to 9.27 with 60 kg P_2O_5 ha^{-1}, compared to only 5.44 in the control. Ahmad et al. (2018) reported 11 seeds per pod at the 60 kg rate. Gezu Degefa et al. (2021) recorded the highest value 30.18 grams at 46 kg P_2O_5 ha^{-1}, while the control was lower at 28.27 grams. Samim et al. (2023) observed an even higher 1000-seed weight: 39.32 grams at 60 kg, compared to 33.88 grams in the control. Ahmad et al. (2018) saw the 1000-seed weight reach 40.2 grams at 60 kg P_2O_5 ha^{-1}. Samim et al. (2023) reported 1.35 t/ha (1350 kg/ha) at 60 kg P_2O_5 ha^{-1}. Ahmad et al. (2018) found a maximum yield of 1139 kg/ha at the same phosphorus rate, much higher than the 645 kg/ha in the control, representing an increase of about 76%. Gezu Degefa et al. (2021) achieved their highest yield, 961.6 kg/ha, at 46 kg P_2O_5 ha^{-1}, while the control produced 766.7 kg/ha. Patel et al. (2022) recorded a yield of 1066 kg/ha with 60 kg P, nearly double the control's 578.9 kg/ha. Finally, Ahmad et al. (2018) noted that biological yield (total biomass) peaked at 4595 kg/ha with 60 kg P_2O_5 ha^{-1}, compared to only 2513 kg/ha in the control.

On a macro level, the cumulative effect on pods and seed weight translates into substantial grain yield gains. Unfertilized yields hovering around 1,000 kg/ha can be elevated to roughly 1,350 kg/ha with 30–46 kg P_2O_5/ha (Bhattacharya et al., 2023; Gezu et al., 2021). Interestingly, yield responses often plateau in this range, with several studies noting that increasing P from 40 kg to 60 kg/ha fails to produce statistically significant further gains (Singh et al., 2015; Roshan et al., 2022). From an economic standpoint, 30 kg P_2O_5/ha is frequently cited as the most efficient rate, offering the best return on investment for smallholder farmers (Chauhan et al., 2023). However this depends on the initial phosphorus status of the soil.

Optimal rates are not universal and are often influenced by genotype and environment. In high-input summer mung bean systems or specific regions, higher rates between 60 and 80 kg P_2O_5/ha have been found to be economically viable and biologically superior (Suman et al., 2021; Mohibullah et al., 2023; Samim et al., 2023). Furthermore, the interaction between P-levels and planting density suggests that as competition for resources increases (higher density), the required phosphorus rate also rises to maintain individual plant productivity (Kaur &

Brar, 2023). In moisture-stressed environments, phosphorus plays a protective role, helping plants maintain pod counts during drought years compared to unfertilized crops (Rathore et al., 2023).

2.9 Interaction Effect of Nitrogen and Phosphorus Rates on Phenology, Growth, Nodulation, Yield and Yield Components of Mung Bean

Nitrogen and phosphorus work together in mungbean (*Vigna radiata L.*) production, the results are way better than using either one alone. Nitrogen kicks things off by driving early canopy development and loading up the leaves with chlorophyll, so the crop gets a strong vegetative start. Phosphorus, on the other hand, really pushes root growth and nodule initiation, which is huge for biological nitrogen fixation later on (Fazil et al., 2024). When you give the crop a balanced dose say, around 20–30 kg of N and 40–60 kg of P per hectare you get rapid early biomass accumulation and solid plant establishment, but you don't run into issues like delayed flowering that pop up when you go overboard on nitrogen.

2.9.1. Interaction Effect of Nitrogen and Phosphorus on Phenology and Growth of Mung Bean

In the specific agricultural landscape of Ethiopia, the interplay between nitrogen (N) and phosphorus (P) is a decisive factor in mung bean productivity. While each nutrient is vital, their interaction often yields results far greater than the sum of their individual parts.

The most visible impact of this synergy is found in plant architecture. In the central highlands, the combination of 40–46 kg N ha^{-1} and 30–40 kg P ha^{-1} has been shown to push plant heights to roughly 60 cm a nearly 40% increase over unfertilized crops (Tana et al., 2021; Demeke et al., 2022). This structural boost is supported by a significant expansion in leaf production and branching. For instance, studies in the Amhara and Oromia regions found that balanced fertilization nearly doubled leaf counts and branch numbers, which are critical precursors to high pod density (Assefa et al., 2020; Demissie et al., 2021; Worku & Tilahun, 2019).

Beyond physical growth, the N×P interaction acts as a biological regulator for the plant's

lifecycle. In the Southern Nations region, a balanced application (40 kg N and 30 kg P ha^{-1}) was found to accelerate flowering and shorten the overall maturity period by about nine days (Gebremariam & Tesfaye, 2022). This early maturity is a vital safeguard in drought-prone areas, allowing the crop to escape late-season moisture stress.

However, this balance is precarious. Research in Tigray and other regions warns that applying high levels of nitrogen (above 60 kg ha^{-1}) without matching phosphorus can actually be detrimental. This imbalance tends to trap the plant in a state of prolonged vegetative growth, delaying flowering and increasing the risk of lodging by as much as 28% (Hagos et al., 2020; Patel et al., 2018).

The internal efficiency of the plant also depends on this nutrient partnership. Evidence from the East Shewa zone and elsewhere indicates that total dry matter and Leaf Area Index (LAI) are maximized when N and P are applied in tandem, often peaking at rates of 45–55 kg N and 35–40 kg P ha^{-1} (Mekonnen & Kibret, 2021; Alemu & Dawit, 2022; Kumar et al., 2017). Furthermore, phosphorus has been shown to improve the agronomic efficiency of nitrogen; as P levels increase, the plant becomes significantly more effective at converting applied nitrogen into grain yield (Getahun et al., 2021).While various international studies have explored even higher application rates sometimes up to 80 kg P ha^{-1} the consensus for Ethiopian agroecology leans toward a more moderate, balanced approach (Fazil et al., 2024; Omran et al., 2018; Rojh et al., 2024). While the primary branching of the plant is largely driven by the main effect of nitrogen (Demeke et al., 2022), the overall vigor and root length of the crop require the chemical "handshake" of both nutrients (Ahmed et al., 2019).

2.9.2. Interaction Effect of Nitrogen and Phosphorus on Nodulation of Mung Bean

The symbiotic relationship between mung bean and nitrogen-fixing bacteria is highly sensitive to the surrounding nutrient landscape, particularly the balance between nitrogen (N) and phosphorus (P). While these nutrients are essential for growth, their interaction determines whether the plant prioritizes biological nitrogen fixation or relies on soil-available nitrogen a trade-off that has significant implications for nodule density, mass, and functional quality.

A consistent theme across recent research is the existence of a "sweet spot" for nutrient application. Modest amounts of "starter" nitrogen (roughly 15–30 kg N ha^{-1}) paired with moderate

phosphorus (20–30 kg P ha^{-1}) typically maximize nodule counts. For instance, studies by Tana et al. (2022), Melkamu et al. (2023), and Singh et al. (2021) all identified peak nodulation ranging from 38 to 48 nodules per plant within these specific ranges.
However, exceeding this threshold often leads to a sharp decline in symbiotic activity. High nitrogen levels (typically >40 kg N/ ha) act as a biological brake; as soil nitrogen becomes abundant, the plant reduces its investment in nodules. This inhibitory effect can be dramatic, with some trials reporting a 40% reduction in nodule counts or a near-total cessation of initiation when phosphorus is also deficient (Nguyen et al., 2022; Tana et al., 2022). Interestingly, even phosphorus has its limits; excessive P application (up to 40 kg ha^{-1}) can occasionally suppress nodulation, suggesting that balanced, site-specific nutrition is more effective than high-input strategies (Melkamu et al., 2023).

Beyond simple counts, the interaction between N and P dictates the physical mass and metabolic health of the nodules. Optimal fertilization typically 20–25 kg N combined with 25–30 kg P ha^{-1} can result in a three- to four-fold increase in both fresh and dry nodule weight compared to unfertilized controls (Worku & Tilahun, 2023; Assefa et al., 2023). In tropical and phosphorus-deficient soils, the role of P is particularly pronounced. Research in these environments shows that while severe phosphorus deficiency renders nodules almost nonexistent, adequate P allows for robust biomass accumulation, even at lower nitrogen rates (Silva et al., 2022; Gebremariam, 2022).

Furthermore, the quality of these nodules is as critical as their quantity. High-quality, "effective" nodules are characterized by their active nitrogen-fixing zones. Researchers such as Dechassa et al. (2023) and Tadesse et al. (2023) have noted that while optimal N and P combinations produce a high percentage of effective nodules (up to 75–80%), an over-reliance on nitrogen shifts the balance toward ineffective, non-functional structures. This highlights the danger of nitrogen-heavy fertilization, which can create the illusion of plant vigor while actually sabotaging the crop's long-term nitrogen-fixing capacity (Rahman et al., 2023).

The effectiveness of chemical N and P is often amplified when integrated with biological management. Seed inoculation with *Rhizobium* and Plant Growth-Promoting Rhizobacteria (PGPR) creates a synergistic effect, enhancing not only nodule count and dry weight but also the overall uptake of nutrients (Neha et al., 2024; Tahir et al., 2020). However, the timing and soil conditions remain vital variables. For example, in the presence of nitrogen fertilizer, the

ability of phosphorus to boost nodule formation is often diminished, whereas, in N-starved soils, P remains the primary driver of root nodule architecture (Sophoanrith & Leangsrun, 2023).

2.9.3. Interaction Effect of Nitrogen and Phosphorus on Yield and Yield Components of Mung Bean

Research across diverse agro-ecological zones consistently highlights the synergistic relationship between nitrogen (N) and phosphorus (P) fertilizers in boosting mung bean productivity. Many studies suggest that a moderate "starter" dose of nitrogen, when paired with higher phosphorus levels, provides the best results. For instance, Fazil et al. (2024) and Iqbal et al. (2020) both found that a combination of 20 kg N ha^{-1} and 40 kg P_2O_5 ha^{-1} significantly enhanced yield attributes, including pod length, grain weight, and total biomass. Similarly, Chattha et al. (2017) achieved a maximum seed yield of 1389.7 kg ha^{-1} by slightly increasing the phosphorus to a 20:50 kg NP ha^{-1} ratio.

In areas with poorer soil quality, higher applications appear necessary. Sophoanrith et al. (2023) and Omran et al. (2018) both identified 40 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1} as the ideal threshold for maximizing grain yield and pod production. Sophoanrith noted that the high response to N was likely due to initially low soil nitrogen levels. Pushing these rates further, Rojh et al. (2024) found that a 40:80 kg ha^{-1} NP ratio was most effective for ensuring high yields over a single growing season.

The statistical nature of this N and P interaction reveals further complexity. Demeke et al. (2020) observed that while the interaction of 23 kg N and 40 kg P ha^{-1} produced the highest grain yield (1902.78 kg ha^{-1}), the interaction effect was not universally significant across all growth metrics. They noted that while N and P individually drove pod count and biomass, their combined effect on those specific components was non-significant. Furthermore, Sophoanrith and Leangsrun (2023) pointed out a unique nuance: increasing phosphorus rates improved grain weight only when nitrogen was absent. Once nitrogen was introduced, the impact of varying phosphorus rates on grain weight became less distinct, though the overall grain yield still benefited from the interaction.

When Nitrogen and Phosphorus are applied together, the effects are dramatic. Vegetative growth accelerates, setting the stage for higher yields. Malik, .et al (2003) demonstrated that

using either nutrient on its own made little difference, but applying 25 kg N ha^{-1} along with 75 kg P_2O_5 ha^{-1} caused plants to grow taller and branch more than ever before. Nitrogen initiates early shoot development, while Phosphorus extends the roots, making it easier for plants to absorb water and nutrients. Khan et al. confirmed this in 2023 with trials in semi-arid fields. Their combination of 20 kg N and 40 kg P_2O_5 per hectare outperformed the controls, producing plants with wider leaves and greater dry matter. This increase in structure allows the plant to support a larger number of pods.

Pods per plant respond most strongly to the N and P interaction. Yin et al. (2018) used a quadratic orthogonal rotation design and pinpointed the effect: the synergy between Nitrogen and Phosphorus is significant ($P<0.01$) for pod retention. Their optimal range was 34–42 kg N and 17–21 kg P_2O_5 per hectare, raising pod numbers above 23.4 per plant, compared to the usual 10–14 in controls. Sadeghipour and colleagues in 2010 went further. With 90 kg N and 120 kg P_2O_5, they achieved 8.61 seeds per pod the highest recorded suggesting that when Phosphorus is abundant, Nitrogen becomes the limiting factor for seed filling.

All these improvements add up. Grain yields rise when both nutrients are applied together, clearly outperforming single-nutrient treatments. Sadeghipour et al. (2010) reached a peak of 2,242 kg ha^{-1} with their high-rate combination far more than either Nitrogen or Phosphorus alone produced. Yin et al. (2018) showed that even without maximum inputs, a moderate 42 kg N and 21 kg P_2O_5 still yielded over 2,141 kg ha^{-1}. Malik's 2003 study offers another perspective: on certain soils, 25 kg N and 75 kg P_2O_5 per hectare resulted in 1,112 kg ha^{-1}, making it the best economic choice for those conditions.

But the benefits go beyond just grain yield. The interaction between N and P also affects total biomass and seed quality. Nitrogen drives protein synthesis, while Phosphorus aids in transporting nutrients into the seeds. Malik et al. (2003) recorded the highest protein content 25.6% with 50 kg N and 75 kg P_2O_5 per hectare. Khan's results indicate that when Nitrogen remains available, plants delay senescence, keeping leaves green longer during pod development and increasing biological yield. Taken together, the evidence is clear: a solid "starter" dose of Nitrogen (20–40 kg) combined with a steady "sustenance" dose of Phosphorus (40–80 kg) gives mung beans the best chance for high yields and strong quality.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The field experiment was done at Pawe Agricultural research center during 2025 cropping season under rain feed condition. Pawe Agricultural Research Center (PARC) is located in the lowlands of the Northwestern Ethiopia, Metekel Zone of Benishangul Gumze Regional State, about 567km away from Addis Ababa. Geographically, the experimental site is located at 11° 15′ North latitude and 36° 30′ East longitude. The altitude of the site is 1120-1200 m.a.s.l. with gentle slope. The area is characterized by gently undulating to undulating plain with an average slope of 5% (Abbute, 1998). The mean annual maximum and minimum temperatures of the site are 32.6 ^{0}C and 16.5 ^{0}C, respectively.

The study area has a uni-modal rainfall pattern that extends from May to October with mean annual rainfall of 1659mm. According to the report of Pawe Agricultural Research Center (2014), the soils of the district have been broadly categorized as *Vertisols* (40-45%); *Nitisols* (25-30%), and *Luvisols* (25-30%). The experimental crop of the study mung bean was done on *Nitisols* (pH from 4.5 to 6). The dominant crops in the study area are soybean, Mung bean maize, rice, groundnut, Finger millet and sesame are the most important and dominant crops according to the orders from the highest to lowest which are grown the area.

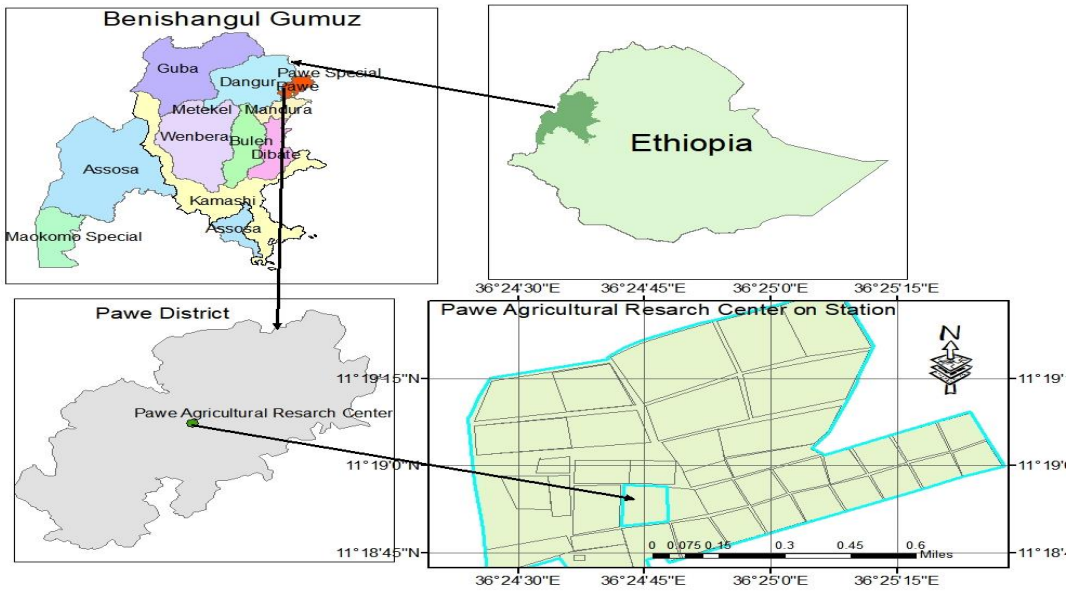


Figure 1: Map of the study area

3.2. Description of Experimental Materials

Mung bean variety N-26 (Rasa) was used for the study. It is released in 2011 by MARC (Dikr, 2023). It was high-yielding improved variety which is adapted to the study agro-ecology of the area. The variety is green in seed color, can be harvested within 60-70 days and its productivity is 900 kg ha^{-1}(Belete et al., 2022). Triple supper phosphate (46% P_2O_5) was used as the source of Phosphorus, while Urea (46% N) was used as source of Nitrogen

3.3. Experimental Treatments and Design

The experiment consisted of a factorial combination of four Nitrogen fertilizer rate (0, 10, 20, and 30 kg/ha N) and five phosphorus fertilizer rate (0, 23, 46, 69 and 92 kg/ha P_2O_5). The experiment was laid out in a randomized complete block design (RCBD) with three replications. The space between row, plot and block were 0.4m, 0.5m and 1m respectively, and the number of rows per treatment was eight rows with 0.4m spacing of each. The numbers of harvestable rows were the middle four rows and leaving border the first and the last eighth rows in order to avoid border effects and the second and seventh rows are used as destructive sample. The total experimental field size was 572m^2 while the individual gross plot size was 2m x 3.2m=6.4 m^2

3.4. Soil Sampling and Analysis

Representative soil samples were collected from the experimental field before sowing at a depth of 0 - 20 cm using an auger in a zigzag pattern. About 20 soil sub-samples were collected from different spots to form a composite soil sample. The subsamples were thoroughly mixed together on flat plastic sheet and collected in clean new plastic bags. The composite soil samples were labeled with necessary information and transported to the Pawe Agricultural Research Institute soil and water analysis laboratory. The soil samples were then air dried, and ground and sieved with a 2 mm size sieve, in preparation for analysis of the envisaged soil physicochemical properties. The soil samples were further ground to pass a 0.5 mm size sieve for the determination of organic carbon and total N contents. The following physicochemical analysis viz, texture, soil pH, cat ion exchange capacity (CEC), Organic carbon (OC), total Nitrogen (TN), and available Phosphorus (Av. P). . The soil textural class distribution was determined using the Bouyoucos hydrometer method (Day, 1965). The pH of the soil was determined at 1:2.5 (weight/volume) soils to water dilution ratio using a glass electrode attached to digital pH meter (Chopra and Kanwar, 1976). Cation exchange capacity (CEC) was determined after saturating the soil with in ammonium acetate (NH4OAC) and displacing it with in NaOAC (Chapman, 1965). Organic carbon was determined by Potassium dichromate method (El-Attar, and Jackson., 1973). Total nitrogen was analyzed by Microkjeldahal method (Walkely and Black 1934). Available phosphorus and sulfur were determined using the Bray II method (Bray and Kurtz., 1945) and (Horneck, 2011) respectively.

3.5. Experimental Procedure

The experimental field was ploughed with tractor to a fine tilth three times and the plots were leveled manually. According to the design, a field layout was made and each treatment was assigned randomly to the experimental units within a block. Mung bean seeds are sown in rows of spacing manually. Then Nitrogen as Urea (46% N) and Phosphorus in the form of Triple Super Phosphate were applied at the time of sowing based on the treatments combination. Weeding was done two times; and harvesting and threshing was done manually.

3.6. Crop Data Collection

The data on plant phenology, growth and yield related traits were recorded from ten sample plants randomly selected from the harvestable rows in each plot. Yield data was also recorded from all plants in the middle four rows excluding plants from the borders row and destructive rows used for nodulation

3.6.1. Phenological Parameters

Days to 50% emergence: was recorded as the number of days from sowing to the date when 50% of the plants in a plot was emerged from the soil.

Days to 50% flowering: was recorded as the number of days from sowing to the date when 50% of the plants in a plot produced at least one flower.

Days to 95% maturity: was recorded as the number of days from the days from sowing to the date when 95% of the plants in a plot are matured. The physiological maturity was determined by the hardness of the pods, the appearance of darkened of the pod

3.6.2. Growth and Nodulation Parameters

Plant height: was recorded by measured from ten randomly selected plants from the harvestable rows using measuring tape from the ground surface to the top of the plant at maturity and the average was calculated (Zelalem *et al*., 2009).

Leaf Area: It was recorded from 10 randomly selected plants from the destructive rows and measured just before flowering using pictorial method as described by Tamado Tana (2015)

Leaf area index (LAI): The leaf area index was calculated as the ratio of total leaf area of the 10 plants to the respective ground area occupied by the crop.

Number of nodule per plant: Number of nodules per plant: Sampling for nodulation was performed by uprooting the roots of 10 plants randomly from the destructive rows of each plot at 50% of flowering stage of the plant. While uprooting remaining nodules in the soil were picked up by hand and the number of nodules per plant had recorded by counting and mean per plant.

Number of Effective nodule: After recording nodule numbers count effective nodules were usually pink or reddish inside when sliced (Shuichi & Hirozo, 1955)

Nodule fresh weight: The nodules were collected from 10 sample plants and pooled from each plot including the dissected nodules for color determination, and their fresh weight was measured by a sensitive balance to constant weight and expressed as an average nodule fresh weight of 10 plants samples were taken as nodule fresh weight per plant. It was reported as gram per plant.

Nodule dry weight: After recording the fresh weight, the same nodules were oven-dried at 70°C for 48hr to determine nodule dry weight (Tesfaye et al,. 2018).

3.6.3. Yield and Yield Related Parameters

Stand count at harvest: was recorded by counting the number of plants at harvest from the net plot.

Number of primary branch per plant: was calculated by counting the number of branches from ten randomly selected plants and averaged to the number of plants considered.

Number of pods per plant: was recorded as the number of pods per plant from ten randomly selected plants from the net plot area and averaged.

Pod length: It was measured in cm by ruler from all 10 tagged sample plants of the three pods length per plant those are randomly selected and the mean length is recorded on each plot.

Number of seeds per pod: The total number of seeds in the pods of 10 plants were counted and divided by the total number of pods to find the number of seeds per pod.

Thousand seed weight (g): was recorded by counting thousand seeds randomly from a bulk of seeds and weighed using a sensitive balance.

Above ground Biomass yield (t/ha): It was determined by taking the weight of 10 randomly taken plants at physiological maturity including the pods from each net plot area after sun drying for 7 days . The average dry biomass per plant was multiplied by the number of total plants in net plot area at harvest and it was expressed as dry biomass in kg/ha.

Seed yield: was weighted the total yield which is harvested from net plot excluded the two outer rows and two destructive rows. The moisture content of the seed yield was adjusted to 10% according to the formula indicated by Abebe, (1979)

$$\textbf{Adjusted yield} = \textbf{Harvested yield} \times \frac{\textbf{100 – Actual Moisture \%}}{\textbf{100 – Standard Moisture\%}}$$

Harvest index (%): Was calculated by dividing seed yield per net plot area by total above-ground dry biomass yield per net plot area and multiplied by 100.

3.7. Data Analysis

All collected data was analyzed using R software When the effect of treatments are significant, the different between treatment mean was determined using Tukey HDS at 5% level of significance. Correlation was analyzed to determine relationship among yield and yield components.

3.8. Partial Budget Analysis

Partial budget analysis was employed for economic analysis of N and P_2O_5 fertilizer and it was carried out for combined yield of data as described by CYMMT, (1988).

Adjusted yield (ADY): was the average yield adjusted downward by a 10% to reflect the difference between the experimental yield and yield of farmers. AjY = AvY- (AvYx0.1) Where, AvY is average experimental yield and AjY is adjusted yield. Unadjusted grain yield (UGY) (kg/ ha^{-1}): is an average yield of each treatment. Gross field benefit (GFB): was computed by multiplying field/farm gate price (120 Birr/kg) that farmers receive for the crop from each plot when they sale it as adjusted yield. GFB = AjY x field/farm gate price for the crop

Total cost: Cost of N and P_2O_5 fertilizer and application cost used for the experiment. Their prices were based on 2025 price during planting Urea/kg = 75.00 Birr and TSP/kg = 90.00 Birr. The costs of other inputs and production practices such as labor cost for land preparation, planting, weeding, crop protection, and harvesting are assumed to remain the same or were insignificant among treatments. Net benefit (NB): were calculated by subtract the total costs from gross field and MRR calculated by change in NB divide by change in TVC multiplied by 100.

4. RESULTS AND DISSCUSSION

4.1. Soil Physico-Chemical Properties of the Experimental Site

The Selected physico-chemical properties of the soil of the experimental site was analyzed for composite soil (0-20 cm depth) samples collected from experimental site before planting and treatment application during 2025 cropping system. The results of pre-planting soil analysis revealed that the soil of the study area was clay in texture (35% sand, 51% clay and 14% silt). The pH of the soil of the experimental site was strongly acidic in reaction with the pH (H2O 1:2.5) value of 5.4 (Tekalign, 1991).

The total N, available P, OC, available S and CEC of the soil before planting were 0.13%, 8.9 PPM mg kg-1, 1.04%, 4.3 mg kg-1(ppm), 23.92 cmol (+) kg-1, respectively (Table 1). According to Landon,(1991) soils are classified depending on their total N content in percentage (%), as low < 0.2, medium 0.2- 0.4, and high > 0.5. Thus, the soil of the study site had low total N content. Similarly available P content classified as the range < 10 low, 10 - 25 medium, and > 35 mg kg-1 high, based on this the study site had low available phosphorus in the soil. According to Walkely and Black (1934) soil total organic carbon rating was very low < 0.5, 0.5 - 1.5 low; 1.5-3.0 as medium and > 3 high. Thus, the organic carbon content of the site soil (1.04) and classified as low organic carbon.

Horneck et al.(2011) classified available S content of the range < 2- very low, 2-5 low, 5-20 medium and >20 high based on this the study site had low S available in the soil. Similarly, the CEC ranges of 5 - 15, 15 -25 and 25-40 cmol kg-1 are rated as low, medium and high, respectively. Based on these ratings the CEC value is rated as midium in the soil. Zinc levels are medium at 0.64 mg/kg (Jones and Benton, 2003), However, the Boron (B) content is very low at 0.16 mg/kg (Horneck, 2011)

Table 1: Physicochemical properties of the experimental site

Parameters	Values	Rating	Reference
pH (H_2O)	5.4	Strongly acidic	Tekalign (1991)
OC (%)	1.04	Low	Walkely and Black 1934
CEC $Cmol_{(+)}\,kg^{-1}$	23.92	Medium	Chapman, 1965
TN (%)	0.13	low	Landon, J.R. 1991
AvP (BrayII) ppm	8.9	Very low	Bray and Kurtz., 1945
AvS	4.3	low	Horneck, 2011
Zn mg/kg (ppm)	0.64	Medium	Jones and J. Benton, 2003
B mg/kg (ppm)	0.16	Very low	Horneck, 2011
Texture			
Clay	51		
Silt	14		Day, 1965
Sand	35		
Textural Class	clay		

Where pH = hydrogen power, % OC = percent of organic carbon, CEC = Cation exchange capacity %TN = Percent of total nitrogen, AvS= available sulfur, Av.P.ppm = available phosphorus in parts per million, Zn = Zinc, B = Boron

4.2. Phenological Parameters

4.2.1. Days to 50 % Emergence

The main effects of nitrogen, phosphorus and their interaction effects were not significant ($P \leq 0.05$) on days to emergence (Appendix Table 1).

Both main effects and interactions have no effect on crop emergence due to of the optimal conditions for seed germination and seedling emergence (soil temperature, moisture and texture) and the quality of seeds used (age and storage condition). This suggests that the effect of imposed treatments on seed germination and seedling emergence is not important as seeds of most plants use their own stored food initially for germination and emergence. As a result, nitrogen and phosphorus fertilizer application had no effect on mung bean emergence. In agreement with this findings Taylor (2020) reported that plants rely more on stored food than on outside nutrients for germination and emergence. Similarly Teame et al. (2017) found that emergence was not significantly affected by nitrogen and phosphorus fertilizer rats because it relies on seed reserves

4.2.2. Days to 50% Flowering

Both the main effects and interaction effects of the factors significantly ($P < 0.001$) influenced the number of days to 50% flowering (Appendix Table 1). Plants in the control group (no added nitrogen or phosphorus) started flower the fast at 39.67 days. On the other hand when they received high nitrogen (30 kg/ha) but no phosphorus flowering was delayed to 50.33 days It was increased by 26.87% from the control and statically similar with 30 kg N/ha with 23 kg P_2O_5/ha, 30 kg N/ha with 46 kg P_2O_5/ha and 20 kg N/ha, 0 kg P_2O_5 (Table 2).

Basically, as the nitrogen increased, plants put more energy into growing leaves and stems, and delay back flowering. Phosphorus, though, played a different role, and its effect depended on how much nitrogen was around. When there wasn't any extra nitrogen (0 kg N/ha), adding high phosphorus (92 kg/ha) slowed down flowering and took 43 days instead of 39.67 days (control treatment). This suggests that the control plants, which got nothing, probably flowered early because they were stressed. While with high phosphorus rate, they could grow at a normal pace. Here, adding phosphorus sped flowering up, reducing it from 50.33 to 47.67 days at high nitrogen level (30 kg/ha). So, phosphorus helped rein in the excessive vegetative growth caused by all that nitrogen and nudged the plants to start flowering earlier. In line with Anjum et al .(2015) reported that the longest days to flower 40 days when they got 40 kg of nitrogen and 60 kg of P_2O_5 per hectare. Although Shegaw (2025) recorded a higher delay of 53.96 days under specific N-P concentrations. Similarly, Shiferaw and Abewoy (2023) and Khan et al. (2017) observed that nitrogen alone extended flowering to between 45 and 46.3 days; however, the inclusion of phosphorus (30–90 kg P_2O_5/ha) mitigated these delays, resulting in earlier flowering (as early as 41.7 days).

Table 2: Interaction effect of nitrogen and phosphorus rates on days to 50% flowering

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	39.67^{j}	43.67^{hi}	43.67^{hi}	43.00^{i}	43.00^{i}	42.6^{d}
10	46.00^{efg}	45.33^{fgh}	45.00^{gh}	44.67^{ghi}	44.00^{hi}	45.0^{c}
20	49.00^{abc}	48.33^{bcd}	47.00^{def}	46.00^{efg}	46.00^{efg}	47.3^{b}
30	50.33^{a}	49.67^{ab}	49.00^{abc}	48.00^{bcd}	47.67^{cde}	48.9^{a}
Mean	46.3^{a}	46.6^{a}	46.2^{a}	45.4^{b}	45.2^{b}	
CV(%): = 1.22						
HSD: = 1.74						

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.2.3. Days to 90 % Physiological Maturity

Number of days to physiological maturity was highly significant ($P > 0.001$) affected by the main effects of nitrogen, phosphorus application and their interaction on mung bean (Appendix Table 1). The analysis of variance indicated that the longest days to mature (78 and 77.67 days) were recorded when Mung bean was grown with 30 kg N/ ha and no added phosphorus, and 20 kg N/ha and 0 kg P_2O_5/ha, and 30 kg N/ ha and 23 kg P_2O_5/ ha, respectively indicate that 13.04% increase from the control (Table 3).

So, more nitrogen in the soil tended to slow things down, pushing maturity later. On the flip side, the fastest maturity happened in the control group, with zero nitrogen and zero phosphorus. Those plants wrapped up in just 69 days, which shows that when nutrients run short, crops hurry up and finish their life cycle. Adding phosphorus usually sped up flowering when nitrogen was high. For instance, with 30 kg N/ha, maturity dropped from 78 days at 0 kg P_2O_5/ha to just 72.33 days when phosphorus hit 69-92 kg P_2O_5/ ha. It looks like phosphorus helped plants grow and reproduce more efficiently, cutting down the extra time that nitrogen alone would have added. The way nitrogen and phosphorus worked together mattered nitrogen's effects depending on how much phosphorus was around. This finding in line with Imran et al. (2015), who observed that excessive nitrogen delays maturity by extending the veg-

etative phase, whereas increasing phosphorus levels accelerates the transition to flowering and ripening. Similarly, Assefa et al. (2020) demonstrated this balancing effect, reporting that plants matured in 74.3 days with 46 kg P_2O_5/ha, whereas high-nitrogen/low-phosphorus treatments significantly extended the maturity period to 81.6 days.

Table 3: Interaction effect of nitrogen and phosphorus rates on days to 90% maturity

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	69.0 ^{g}	72.7^{def}	72.3^{ef}	71.3^{f}	71.0^{fg}	71.3^{c}
10	76.0^{ab}	74.3^{bcde}	73.0^{cdef}	71.7^{f}	71.3^{f}	73.3^{b}
20	77.7^{a}	76.3^{ab}	75.0^{bc}	74.3^{bcde}	71.3^{f}	74.9^{a}
30	78.0^{a}	77.7^{a}	74.7^{bcd}	72.3^{ef}	72.3^{ef}	75.0^{a}
Mean	75.2^{a}	75.3^{a}	73.8^{b}	72.4^{c}	71.5^{d}	
CV (%) =	0.89					
HSD =	2.03					

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.3. Growth Parameters

4.3.1. Plant Height

Analysis of variance indicated that nitrogen and phosphorus fertilizer rates ($P\leq 0.001$) and their interaction ($P\leq 0.01$) had highly significant effect on mung bean plant height (Appendix Table 2). The tallest plants were noted at the combined application of 30 kg N/ha and 92 P_2O_5 kg/ha (57.77 cm), resulted in a 135.92% increase over the control which was statistically at par with 20 kg N/ha, 92 P_2O_5 kg/ha (56.43 cm) and 30 kg N/ha, 69 P_2O_5 kg/ha (55.87 cm). Conversely, the shortest plants were observed in the control plot at (24.53 cm) (Table 4).

This indicates that combined application nitrogen and phosphorus actually increase plant height Nitrogen helps the plant stretch out, while phosphorus gives the support and energy it needs to pull it off. This in line with Assefa et al. (2020) Observed that mung beans grew taller when both nitrogen and phosphorus were applied together they explained that nitrogen gets the cells dividing and elongating, and phosphorus supports root growth and energy for all that

action. Mekonnen and Kibret (2021) similarly they obtained the tallest plants (58.4 cm) when they used 46 kg each of nitrogen and phosphorus per hectare, compared to control (38.2 cm). Wedajo (2015) also observed that the tallest plants and most primary branches were occurred with the highest combined rates of nitrogen and phosphorous fertilizer.

Table 4: Interaction effect of nitrogen and phosphorous rates on plant height

N kg/ha	P_20_5 kg/ha					
	0	23	46	69	92	Mean
0	24.5^{i}	29.4^{h}	31.3^{gh}	38.1^{ef}	40.5^{e}	32.8^{d}
10	35.4^{fg}	39.0^{ef}	41.7^{de}	50.0^{bc}	50.6^{bc}	43.4^{c}
20	35.2^{fg}	38.8^{ef}	46.1^{cd}	54.5^{ab}	56.4^{a}	46.2^{b}
30	41.3^{e}	42.5^{de}	48.9^{c}	55.9^{a}	57.8^{a}	49.3^{a}
Mean	34.1^{d}	37.4^{c}	42.0^{b}	49.6^{a}	51.3^{a}	
CV (%) = 3.55						
HSD = 4.73						

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.3.2. Number of Primary Branches per Plant

The analysis of variance indicated that the main effect of nitrogen, phosphorus and their interaction had very highly significant ($P\leq0.001$) affected Number of primary branches per plant (Appendix Table 2). The highest number of branch was recorded at 30 kg N/ha with 92kg P_2O_5/ha (9.07) which was statically similar with 20 kg N/ha with 92 kg P_2O_5/ha and 30 kg N/ha with 69 kg P_2O_5/ha. The lowest branch results from control plot (1.67) decreased by 435.29% from the highest branch number (Table 5).

Nitrogen was important here it stimulating lateral bud development and breaking apical dominancy leading to more branches. As phosphorus rate increased from 30 kg N/ha and 0 kg P_2O_5/ha (3.67 branches) to 30 kg N/ha and 92 kg P_2O_5 (9.07 branches) number of branches showed an incredible increases. Just pumping in nitrogen isn't enough; there is a need of plenty of phosphorus to actually branching take off. In line with Dikr and Garkebo (2022) found that the maximum plant height and branches/plant were achieved by applying phospho-

rus at a rate of 60 kg P_2O_5/ha. Mekonnen et al. (2022) observed that increasing both nitrogen and phosphorus led to more primary branches per plant. Nitrogen gets the buds going, and phosphorus backs it up by providing structure and helping the plant absorb nutrients, so those new branches actually stick around. Similarly Chattha et al. (2017) observed that most branches per plant (7.6) from plots with 20 kg N and 50 kg P_2O_5 per hectare and the control group produced 4.2 branches per plant.

Table 5: Interaction effect of nitrogen and phosphorous on branch number

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	1.7^{j}	2.3^{ij}	2.7^{hij}	3.7^{fgh}	4.3^{efg}	2.9^{d}
10	2.7^{hij}	3.7^{fgh}	4.0^{efg}	4.7^{def}	6.7^{bc}	4.3^{c}
20	3.3^{ghi}	4.3^{efg}	5.0^{de}	7.0^{b}	8.7^{a}	5.7^{b}
30	3.7^{fgh}	5.7^{cd}	6.3^{bc}	8.3^{a}	9.1^{a}	6.6^{a}
Mean	2.8^{e}	4.0^{d}	4.5^{c}	5.9^{d}	7.2^{a}	
CV (%) =7.08						
HSD = 1.07						

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.3.3. Leaf Area

The analysis of variance revealed that the main effect and interaction effect of nitrogen and phosphorus on leaf area was highly significant ($P<0.001$) (Appendix Table 2). The maximum leaf area was recorded at the combined application of 30 kg N/ ha and 92 kg P_2O_5/ ha (2546.67 cm²) which was statically at par with 30 kg N/ ha and 69 kg P_2O_5/ ha and it was increased by 223.7% from the control (786.67 cm²) (Table 6).

Leaf area increases dramatically because nitrogen and phosphorus are central to plant growth and cell creation. Nitrogen forms key components like chlorophyll, amino acids, and RuBisCO all crucial for cell division and expansion. When plants receive more nitrogen, they boost photosynthesis and develop a larger canopy. Phosphorus works in cycle, supporting energy transfer through ATP production and aiding in the synthesis of nucleic acids. These functions support the high metabolic needs of rapidly growing leaf tissue. In essence, higher

nitrogen and phosphorus allow plants to produce leaves more quickly and on a larger scale. In line with Ge et al. (2025) who reported that synergistic N-P co-application significantly enhanced leaf nutrient content, SPAD values, and photosynthetic efficiency in mung bean, with leaf nutrients serving as the central hub linking photosynthetic performance to biomass accumulation.

Table 6: Interaction effect of nitrogen and phosphorous on leaf area

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	786.7^{k}	906.7^{jk}	1093.3^{ij}	1320.0^{ghi}	1506.7^{efg}	1122.7^{d}
10	1186.7^{hij}	1440.0^{fgh}	1640.0^{ef}	2200.0^{bc}	2320.0^{ab}	1757.3^{c}
20	1773.3^{de}	2000.0^{cd}	2266.7^{abc}	2360.0^{ab}	2426.7^{ab}	2165.3^{b}
30	2266.7^{abc}	2346.7^{ab}	2440.0^{ab}	2533.3^{a}	2546.7^{a}	2426.7^{a}
Mean	1503.3^{d}	1673.3^{c}	1860.0^{b}	2103.3^{a}	2200.0^{a}	
CV(%) =5.18						
HSD =300.56						

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.3.4. Leaf Area Index

The main effect and their interaction of nitrogen, phosphorus was very highly significant ($P\leq0.001$) affected leaf area index (Appendix Table 2). The maximum leaf area index was achieved from the application of 30 kg N/ha and 92 kg P_2O_5/ha (6.37) which is statically similar with 30 kg N/ha and 69 kg P_2O_5/ha (6.33) threefold above the control (1.97). (Table 7)

The increase in leaf area index with higher nutrient level indicates that Nitrogen is promoting vigorous vegetative growth and chlorophyll production, expanding the canopy. Phosphorous likely compliment this by enhancing root growth, allowing the plant to support large leaf area. It is notable that at zero nitrogen, increasing P only marginally improved LAI (from 1.97 to 3.77), but at 30 kg N/ha, the LAI started high and remained high, showing that Nitrogen is the primary driver for leaf expansion, but Phosphorus is required to maximize it. These lines up with Sharma et al. (2021) observed LAI climbed sharply with more nutrients. They obtained a top LAI of 4.85 at 40 kg N /ha, compared to only 2.15 in their control, and pointed to

nitrogen-driven canopy growth as the reason. Similarly Zewide et al. (2018) indicate that when they combined Nitrogen and Phosphorus LAI increased by 223% over the control

Table 7: Interaction effect of nitrogen and phosphorus on leaf area index

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	1.97^{k}	2.3^{jk}	2.7^{ij}	3.3^{ghi}	3.8^{efg}	2.8^{d}
10	2.9^{hij}	3.6^{fgh}	4.1^{ef}	5.5^{bc}	5.8^{ab}	4.4^{c}
20	4.4^{de}	5.0^{cd}	5.7^{abc}	5.9^{ab}	6.1^{ab}	5.4^{b}
30	5.7^{abc}	5.9^{ab}	6.1^{ab}	6.3^{a}	6.4^{a}	6.1^{a}
Mean	3.6^{d}	4.2^{c}	4.7^{b}	5.3^{a}	5.5^{a}	
CV (%)	=5.18					
HSD	=0.75					

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.4. Nodulation Parameters

4.4.1. Total Number of Nodules

The analysis of variance showed that the main effect of nitrogen, phosphorus and their interaction were very highly significant ($P \leq 0.001$) (Appendix Table 2). As from the analysis of variance indicate that the highest total nodule number was observed at 0 kg N/ha and 92 kg P_2O_5/ha (43) per plant followed by 0 kg N/ha and 69 kg P_2O_5/ha (37.6). It was increased by 54.12% from the control but, as nitrogen level increased the nodulation dropped, regardless of how much phosphorus is around. The lowest nodule number was obtained at 30 kg N/ha /0 kg P_2O_5/ha, (3.53) nodules. (Table 8)

This indicates that when the plant has abundant soil nitrogen it suppress the symbiotic relationship with rhizobia because the energy cost of maintaining nodule is higher than simply then available soil nitrogen. However within nitrogen level zero adding phosphorus significantly boosted nodulation confirming that phosphorous is vital for nodulation initiation and development when the biological nitrogen fixation is active. In lines with Yisehak et al. (2017), who found 41.2 nodules per plant at 0 kg N/ha and 69 kg P_2O_5/ha. Meena et al.

(2022) and Ferguson et al. (2021) confirmed that while phosphorus application linearly increases nodule count and mass by supplying energy for fixation, higher doses of mineral nitrogen significantly suppress nodulation.

Table 8: Interaction effect of nitrogen and phosphorous on total nodule number

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	27.9^{c}	29.4^{c}	29.7^{c}	37.6^{b}	43.0^{a}	33.5^{a}
10	18.8^{def}	18.6^{ef}	22.3^{d}	20.3^{de}	27.2^{c}	21.4^{b}
20	13.4^{gh}	12.1^{hi}	16.4^{fg}	16.6^{fg}	19.2^{def}	15.5^{c}
30	3.5^{l}	5.9^{kl}	7.5^{jk}	8.3^{jk}	9.9^{ij}	7.0^{d}
Mean	15.9^{d}	16.5^{d}	18.9^{c}	20.7^{b}	24.8^{a}	
CV (%)	= 5.86					
HSD	= 3.52					

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.4.2. Number of Effective Nodules

The analysis of variance indicated that the main effect of nitrogen, phosphorus and their all interaction were very highly significant ($P\leq0.001$) (Appendix Table 2). The maximum effective nodulation occurred at 0 kg N/ha and 92 kg P_2O_5/ha, (39.10), while high nitrogen application (30 kg N/ha) without Phosphorus severely reduced efficacy dropping the value to 2.4 (Table 9)

The effectiveness of nodulation is highly sensitive to nitrogen availability the data suggest that at nitrogen zero nearly all formed nodule where effective this efficacy is is driven by phosphorus which aide in energy intensive process of nitrogen. The sever reduction at high nitrogen indicate that high inorganic nitrogen application renders the biological fixation system redundant fixation. Massa et al. (2017) noticed that adding phosphorus (at 46–69 kg P_2O_5/ha) really boosted nodule size and effectiveness, but only when mineral nitrogen stayed low. Razzaque et al. (2012) found that once nitrogen applications get above 20–40 kg/ha, the communication between roots and bacteria basically shuts down. Sophoanrith et al. (2022) similarly nitrogen and phosphorus together are the main drivers of healthy plant-bacteria

partnerships, especially in sandy soils. Owla et al. (2006) and Singh & Pareek (2003) both observed that higher phosphorus levels lead to more active, pink (leghaemoglobin-rich) nodules because phosphorus gives the energy needed for nitrogenase to do its job.

Table 9: Interaction effect of nitrogen and phosphorus on effective nodule number

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	21.2^{cd}	23.9^{c}	24.2^{c}	32.9^{b}	39.1^{a}	28.3^{a}
10	12.9^{ghi}	13.9^{fgh}	18.9^{de}	15.7^{efg}	21.6^{cd}	16.6^{b}
20	10.9^{hij}	10.2^{ij}	14.5^{fgh}	14.6^{fgh}	17.2^{ef}	13.5^{c}
30	2.4^{l}	4.9^{kl}	5.4^{kl}	6.0^{kl}	7.4^{jk}	5.2^{d}
Mean	11.9^{d}	132^{d}	15.7^{c}	17.3^{b}	21.3^{a}	
CV (%) 7.52						
HSD 3.71						

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.4.3. Nodules Fresh Weight

The analysis of variance indicated that the main effect of nitrogen, phosphorus had very highly significant ($P\leq0.001$) and their interaction were non- significant (Appendix Table 2). The maximum nodule fresh weight (0.4) was observed from the application of 0 kg N/ha while the lowest number (0.08) was obtained from 30 kg N/ha (Table 10). The possible reason for these might be due to essentially, the plant "shuts down" its nitrogen-fixing organs because it can more easily satisfy its nutrient requirements from the fertilizer provided. This finding in line with Gebrehana and Dagnaw (2020) reported that significant reductions in nodule parameters as nitrogen levels increase they explain that high levels of available soil nitrogen lead the plant to suppress its symbiotic relationship with *Rhizobium* to save energy.

Regarding phosphorous application the highest nodule fresh weight (0.3) was observed from the application of 92 kg P_2O_5 /ha while the lowest nodule fresh weight (0.2) from 0 kg P_2O_5 /ha (Table 10). The possible reason for the highest nodule fresh weight by phosphorous application might be due to higher phosphorus availability supports better nodule tissue devel-

opment and bacterial multiplication. In line with Nuru Seid (2020) and Worku et al. (2022) indicated that increasing phosphorus rates significantly enhanced nodule fresh weight. They explained that phosphorus is vital for the multiplication of Rhizobia and the development of host plant root tissues, which directly increases the size and weight of individual nodules.

Table 10: Main effect of nitrogen and phosphorus on nodule fresh weight

Treatments	Nodule fresh weight
Nitrogen rate (kg/ha)	
0	0.4[a]
10	0.3[b]
20	0.2[c]
30	0.08[d]
HSD	0.025
Phosphorous rate (kg/ha)	
0	0.2[c]
23	0.2[c]
46	0.24[b]
69	0.25[b]
92	0.3[a]
HSD =	0.030
CV (%) =	11.3

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.4.4. Nodules Dry Weight

The analysis of variance indicated that the main effect of nitrogen and phosphorus had very highly significant ($P\leq0.001$) and their interaction was significant ($P\leq0.05$) (Appendix Table 2). The analysis of variance showed that the nodule dry weight was highest at 0 kg N/ha and 92 kg P_2O_5/ha (0.066) which was statically par with 0 kg N/ha /69 kg P_2O_5/ha (0.052) and the lowest weight was recorded up at 30 kg N/ha and 0 kg P_2O_5/ha (0.002) (Table 10).

Heavier nodules imply that more active bacteroids and leghemoglobin content. The data confirms that to maximize biological nitrogen fixation (indicated by high nodule weight), Nitro-

gen fertilizer should be minimized or avoided, while Phosphorus should be maximized. The application of 30 kg N/ha resulted in negligible nodule mass, confirming that the plant shifted its strategy entirely to mineral nitrogen uptake rather than symbiotic fixation. In lines with Amare et al. (2015) and Worku and Astatkie (2011) observed that phosphorus application increasing nodule growth going, while too much nitrogen just shuts it down. Nitrogen fertilizer just kills the natural fixation process. Similarly Ahmed et al. (2022) observed that adding nitrogen at 40 kg per hectare dropped nodule dry weight to 0.045 grams per plant. On the other hand, applying phosphorus at 60 kg per hectare (with no nitrogen at all) bumped nodule weight up to 0.180 grams per plant.

Table 11: Interaction effect nitrogen and phosphorous on nodule dry weight

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	0.04^{cd}	0.05^{bcd}	0.05^{bc}	0.052^{b}	0.07^{a}	0.05^{a}
10	0.03^{efg}	0.03^{fg}	0.04^{de}	0.04^{de}	0.04^{bcd}	0.04^{b}
20	0.02^{gh}	0.02^{gh}	0.02^{fg}	0.03^{fg}	0.03^{ef}	0.02^{c}
30	0.002^{j}	0.01^{ij}	0.01^{ij}	0.01^{hi}	0.01^{hi}	0.01^{d}
Mean	0.02^{c}	0.02^{c}	0.03^{b}	0.03^{b}	0.04^{a}	
CV (%)	=10.44					
HSD	= 0.010					

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.5. Yield Components and Yield Parameters

4.5.1. Plant Stand Counts at Harvest

The analysis of variance showed that main effects of Nitrogen and Phosphorus fertilizers rates and their interactions had non-significant effect on plant stands count at harvest (Appendix Table 3). Several factors contribute to achieving and maintaining a uniform plant stand count. The possible reason may be seed quality; properly prepared soil, optimal planting condition, uniform thinning practice; pests and disease control were some of the factors achieving uniform plant stand count. In line with this study Sefera et al. (2021) reported that nitrogen and phosphorus fertilizer rates had no significant influence on plant stand count at

harvest. They attributed effective stand establishment primarily to seed viability, proper sowing depth, and initial soil moisture conditions rather than the nutrient treatments applied

4.5.2. Number of Pods per Plant

Analysis of variance showed that the main effect of nitrogen, phosphorous and all their interaction were highly significantly ($p \leq 0.001$) affected the number of pods per plant for mung bean plant (Appendix Table 3). The result showed that the highest number of pod was recorded at the maximum treatment combination of 30 kg N/ha with 92 kg P_2O_5/ha yielding 30.33 pod per plant which was statically at par with 30 kg N/ha and 69 kg P_2O_5/ha and it was seven fold increased from the control (4.33) (Table 11).

Nitrogen helps the plant branch out, providing more places for flowers to form. However, making flowers uses up a lot of the plant's energy. That's where phosphorus comes in, boosting the roots so the plant can take in more water and nutrients which is exactly what those developing flowers require. At 30 kg N/ha with 92 kg P_2O_5/ha, there's a noticeable increase in the number of pods formed (30.33 pods), indicate that phosphorus as the main factor in reducing flower abortion. When plants had ample nitrogen but not enough phosphorus, they started off well, producing many flowers. But without enough phosphorus to back them up, a lot of those flowers didn't survive. This finding similar with Khan et al. (2017) who reported up to 28.5 pods per plant when they used 90 kg of phosphorus per hectare ,which was way more than the 14.2 pods they counted in the control group. Another study by Nigus et al. (2016) found similar results. With 23 kg of nitrogen and 46 kg of phosphorus per hectare, they got 28.6 pods per plant. So, no doubt about it phosphorus is key for pod development

Table 12: Interaction effect of nitrogen and phosphorous on number of pods per plant

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	4.3^{l}	7.7^{k}	8.7^{jk}	10.3^{ijk}	15.7^{h}	9.3^{d}
10	12.0^{i}	15.7^{h}	17.6^{fgh}	18.7^{efg}	23.7^{cd}	17.5^{c}
20	10.0^{ijk}	16.2^{gh}	20.3^{ef}	26.3^{bc}	28.7^{ab}	20.3^{b}
30	11.0^{ij}	17.3^{gh}	21.3^{de}	27.7^{ab}	30.3^{a}	21.5^{a}
Mean	9.3^{e}	14.2^{d}	16.9^{c}	20.8^{b}	24.6^{a}	
CV: 5.13						

HSD: 2.73

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.5.3. Average Pod Length

Analysis of variance showed that the application of nitrogen and phosphorus fertilizer rates and their interactions were highly significantly ($P\leq 0.001$) (Appendix Table 3).The shortest Average pod length was observed at control group (7.07 cm) which was 72.98% decreased from the plot receiving 30 kg N/ha and 92 kg P_2O_5/ha (12.23cm) that is statically similar with 10 kg N/ha and 92 kg P_2O_5/ha, 20 kg N/ha and 92 kg P_2O_5/ha (Table 12).

This implies that nitrogen and phosphorus work better together. Even when there's no added nitrogen, increasing phosphorus alone pushes pod length from 7.07 cm (0 kg P_2O_5/ha) to 10.60 cm (92 kg P_2O_5/ha). The boost slows down after 46 kg P_2O_5/ha, but phosphorus still helps a lot it seems to lift a key barrier to pod growth, probably by giving plants more energy (ATP) and helping them build reproductive tissues. Phosphorus gives roots a boost and helps with energy, which lets plants soak up and use nitrogen more efficiently. This is in line with Tana et al. (2021) observed that adding phosphorus up to the right level made mung bean pods longer, thanks to better nutrient distribution and more cell growth when nitrogen was around to supply protein. Assefa et al. (2020) found similar result pod length in their study went from 6.8 cm in control plots to a max of 9.4 cm when both 46 kg N and 46 kg P per hectare were applied together.

Table 13: Interaction effect nitrogen and phosphorous on pod length

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	7.1^{h}	9.7^{efg}	10.2^{defg}	10.6^{bcdef}	10.6^{bcdef}	9.6^{c}
10	9.2^{g}	10.4^{cdefg}	10.7^{bcdef}	10.8^{bcdef}	11.5^{abcd}	10.5^{b}
20	10.5^{bcdefg}	10.8^{bcdef}	10.9^{abcde}	10.7^{bcdef}	11.7^{ab}	10.9^{ab}
30	9.5^{fg}	11.1^{abcd}	11.3^{abcd}	11.6^{abc}	12.2^{a}	11.1^{a}
Mean	9.1^{c}	10.5^{b}	10.8^{b}	10.9^{b}	11.5^{a}	
CV: =4.09						
HSD: =1.34						

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.5.4. Number of Seeds per Pod

The analysis of variance indicated that the main effect of nitrogen, phosphorus had very highly significant ($P\leq0.001$) and their interaction was non- significant for mung bean crop (Appendix Table 3). The highest number of seeds per pod (12.1) was recorded at the application of 30 kg N/ha In contrast, the lowest number of seed per pod (9.9) was recorded from the control group followed by low input (Table 13). The possible reason for this might be due to Nitrogen is a primary component of chlorophyll and proteins; therefore, higher application rates likely led to a more robust canopy and a more efficient "source-to-sink" relationship. This increased availability of photosynthates (sugars) during the reproductive phase allows the plant to sustain more developing embryos within each pod, thereby reducing seed abortion and increasing the final seed count per pod. This finding In line with Saha et al. (2024) who reported that application of 25 kg N/ha produced the highest number of seeds per pod (12.57), while the control treatment (no nitrogen) recorded significantly lower values.

Regarding to phosphorous fertilizer application the maximum number of seed per pod (12) was obtained from 92 kg P_2O_5/ha which was statically par with 69 kg P_2O_5/ha while the lowest number of seed per pod (8.7) was observed from no application of phosphorus (Table 14) the possible reason incremental increase in the number of seeds per pod might be due to phosphorus-driven increase lies in the nutrient's influence on pollination and grain filling. Adequate phosphorus ensures that the plant has the energy required for the successful fertilization of ovules and the subsequent development of those ovules into mature seeds. In line with Imran et al, (2015) who reported that plots treated with 80 kg P_2O_5/ha produced maximum seeds per pod (11**)** compared to the control plots. Additionally, seeds per pod at 80 kg P_2O_5/ha was statistically at par with 100 kg P_2O_5/ha

Table 14: Main effect of nitrogen and phosphorous on number of seeds per pod

Treatments	Number of seed per pod
Nitrogen rate (kg/ha)	
0	9.9[c]
10	11.1[b]
20	11.5[b]
30	12.1[a]
HSD	0.58
Phosphorous rate (kg/ha)	
0	8.7[d]
23	11[c]
46	11.5[bc]
69	12[ab]
92	12.6[a]
HSD =	0.69
CV (%) =	5.3

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.5.5. Thousand Seed Weight

The analysis of variance indicated that the main effect of nitrogen was very highly significant ($P\leq0.001$), the main effect of phosphorus was significant ($P\leq0.05$) and all their interaction was non- significant to mung bean crop (Appendix Table 3). The highest thousand seed weight (51.1g) was achieved from 30 kg of nitrogen per hectare, whereas the lowest thousand seed weight (48.3g) was recorded in control treatments (Table 15). This might be due to the nutrient's role in the "source-to-sink" relationship. Nitrogen is essential for maintaining a high leaf area index and extending the "stay-green" period of the plant. By delaying leaf senescence (aging), nitrogen allows the plant to continue photosynthesizing for a longer duration during the grain-filling stage. This results in a greater accumulation of carbohydrates and proteins within the seeds, leading to "bolder" or heavier seeds. This finding In line with Saha et al. (2024) , who reported that application of 25 kg N/ha produced the highest thousand seed weight (49.03 g), while the control treatment (no nitrogen) recorded significantly lower values.

Regarding to phosphorous fertilizer application the maximum thousand seed weight was obtained from 92 kg P_2O_5/ha which was statically similar with 69 kg P_2O_5/ha while the lowest thousand seed weight was observed from no phosphorous application (Table 15) the possible reason for this might be due to the final stages of a plant's life cycle, a large amount of energy is required to translocate stored nutrients from the stems and leaves into the developing seeds. Adequate phosphorus ensures this transfer is efficient, resulting in well-filled, dense seeds rather than shriveled ones. This finding In line with Springer (2025) reported that P at 60 kg ha^{-1} produced significantly higher 1000-seed weight (48.23 g), with the effect of 40 kg P ha^{-1} being statistically at par with 60 kg P ha^{-1} . Similarly, Siddiqui et al. (2024) found that application of 60 kg P ha^{-1} combined with Rhizobium inoculation resulted in a test weight of 49.86 g, significantly higher than the control

Table 15: Main effect of nitrogen and phosphorous on thousand seed weight

Treatments	Thousand seed weight
Nitrogen rate (kg/ha)	
0	48.3^{c}
10	49.4^{bc}
20	50.7^{ab}
30	51.1^{a}
HSD	1.7
Phosphorous rate (kg/ha)	
0	48.6^{b}
23	49.5^{ab}
46	49.8^{ab}
69	50.6^{a}
92	51.1^{a}
HSD	1.2
CV (%)	3.4

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.5.6. Aboveground Dry Biomass Yield

Analysis of variance showed that the main effect of nitrogen, phosphorous and their interaction were highly significantly ($p \leq 0.001$) affected Above ground biomass of mung bean plant (Appendix Table 3).The Maximum biological yield (5541.1 kg) per hectare was obtained from the plot received at 30kg N/ha and 92 kg P_2O_5/ha which was statically at par 30 kg N/ha and 69 kg P_2O_5/ha treatment produced 5131.3 kg per hectare. On the other end, the control plots (0kg N/ha and 0 kg P_2O_5/ha) 2016.2 kg per hectare (Table 14).

The substantial increase in biomass at higher nutrient indicate that the crop respond vigorously to vegetative growth when stimulation provided by nitrogen, while phosphorous supported root development and energy transfer leading to higher overall plant dry matter . Alemu et al. (2018), reported that the combined application of 23 kg N /ha and 40 kg P_2O_5/ ha produced the highest aboveground biomass yield. Likewise, Tadesse and Gebremedhin (2020) observed that increasing nitrogen up to 30 kg N/ ha in combination with 46 kg P_2O_5/ ha significantly increased mung bean biological yield.

Table 16: Interaction effect of nitrogen and phosphorous on aboveground dry biomass yield

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	2016.2^{l}	2230.1^{kl}	2499.6^{jk}	2771.9^{hij}	3507.5^{fg}	2605.1^{c}
10	2670.1^{ij}	3704.1^{ef}	3868.7^{ef}	4071.8^{de}	4413.9^{cd}	3745.7^{b}
20	2724.4^{ij}	2941.5^{hi}	3783.8^{ef}	4401.0^{cd}	4689.3^{c}	3708.0^{b}
30	3180.1^{gh}	3703.8^{ef}	4644.8^{c}	5131.3^{b}	5541.1^{a}	4440.2^{a}
Mean	2647.7^{e}	3144.9^{d}	3699.2^{c}	4094.0^{b}	4537.9^{a}	
CV: 3.63%						
HSD: 408.93						

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.5.7. Grain Yield

The main effects of nitrogen and phosphorus, and their interactions effect were highly significantly ($P \leq 0.001$) affected seed yield of mung bean plant (Appendix Table 3). The highest grain yield (1755.7 kg/ha) was achieved from the application of 30 kg N/ha and 92 kg

P_2O_5/ha treatments which was statically similar with 30 kg N/ha and 69 kg P_2O_5/ha and it was 217.95% increases from the control (552.2 kg/ha) (Table 15).

This noticeably clarifies the strong synergistic interaction phosphorus is a critical enabler for nitrogen utilization. Without enough Phosphorous the plant cannot efficiently convert applied Nitrogen into grains, likely due to limits in energy metabolism (ATP from Phosphorous is required for nitrate reduction and assimilation), root proliferation, and general metabolic activity. In line with Alemu et al. (2018) reported that the application of 23 kg N ha^{-1} combined with 40 kg P_2O_5 ha^{-1} produced the highest grain yield of about 1900 kg ha^{-1}, under irrigation condition which was significantly higher than yields obtained from either nutrient applied alone and from the control treatment. Similarly, Tadesse and Gebremedhin (2020) observed that increasing nitrogen from 0 to 23 kg ha^{-1} without phosphorus resulted in only a moderate yield improvement (below 1000 kg ha^{-1}), whereas the combined application of 23 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} increased mung bean grain yield to approximately 1700–1800 kg ha^{-1}. Chattha et al. (2017) similarly obtained that at 20 kg N and 50 kg P2O5/ha per hectare gave them 1389.7 kg/ha way ahead of the 620.5 kg/ha in their control plots. Demeke et al. (2020) Showed that the combination of 23 kg N /ha and 40 kg P/ ha gave the highest grain yield (1902.78 kg ha^{-1}).

Table 17: Interaction effect of nitrogen and phosphorous on grain yield

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	Mean
0	552.2^{k}	632.6^{jk}	750.2^{ij}	859.4^{hi}	1123.7^{g}	783.6^{d}
10	766.8^{i}	1149.9^{fg}	1188.1^{fg}	1236.9^{fg}	1371.6^{de}	1142.7^{c}
20	791.1^{i}	869.7^{hi}	1259.2^{ef}	1511.7^{c}	1594.5^{bc}	1205.2^{b}
30	965.8^{h}	1136.3^{fg}	1487.4^{cd}	1643.1^{ab}	1755.7^{a}	1397.7^{a}
Mean	768.9^{e}	947.1^{d}	1171.2^{c}	1312.8b	1461.4^{a}	
CV = 3.59 %						
HSD= 126.2						

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, ns: non-significant.

4.5.9. Harvest Index

Analysis of variance showed that the main effect of nitrogen, phosphorous and their interaction were highly significantly ($p \leq 0.001$) affected the HI of mung bean plant (Appendix Table 3). The highest Harvest Index (HI) 34.37% was recorded at the combination of 20 kg N/ha and 69 kg P_2O_5/ha, which was statically similar to the treatment of 20 kg N/ha and 92 kg P_2O5/ha, (34.04%). Conversely the lowest HI (27.38%) was observed in the control plot (Table 16).

These indicated that nutrient starvation restricts the crop ability to translocate dray mater in grain. It is important to note that while the highest nitrogen 30 kg N/ha produce the maximum over all biomass, it resulted in slightly lower HI compared to the 20 kg N/ha level. These suggests that increasing nitrogen beyond 20 kg /ha promote excessive vegetative growth that does not proportionately trans located in to grain weight, making the N 20 level the most physiologically efficient rate for biomass partitioning. In lines with Singh et al. (2021) noticed that more overall growth with more nitrogen, but the HI levels off or even drops at really high rates. Too much nitrogen makes the plants grow lush and green, but the grain doesn't always keep up. Fantaye and Gebrezgiher (2016) observed that best HI, 36.4%, obtained with 23 kg N/ha and 46 kg P_2O_5/ha.

Table 18: Interaction effect nitrogen and phosphorous on harvest index

N kg/ha	P_2O_5 kg/ha					
	0	23	46	69	92	mean
0	27.4^{f}	28.4^{ef}	30.1^{cdef}	31.1^{bcde}	32.1^{abc}	29.8b
10	28.7^{ef}	31.0^{bcde}	30.7^{bcde}	30.4^{cde}	31.0^{bcde}	30.4^{b}
20	29.1^{def}	29.6^{cdef}	33.4^{ab}	34.4^{a}	34.0^{a}	32.1^{a}
30	30.4^{cde}	30.7^{bcde}	32.0^{abc}	32.0^{abc}	31.7^{abcd}	31.4^{a}
mean	28.9^{b}	29.9^{b}	31.5^{a}	32.0^{a}	32.2^{a}	
CV = 3.03%						
HSD = 2.91						

Means followed by the same letter are not significantly different ($p<0.05$), HSD: Honestly Significant Difference, CV: Coefficient of Variation, Ns: non-significant.

4.6. Correlation Between Growth, Yield Components, and Yield of Mung Bean

The data shows positive links between the agronomic traits studied, all significant at $p<0.001$. Most of these relationships are linear so, as one trait goes up, the others do too. The most striking result in the dataset is the almost perfect correlation between Grain Yield and Above Ground Dry Biomass Yield, with a correlation coefficient of r = 0.99***. In other words, grain yield depends almost entirely on how much total plant biomass the crop puts on; bigger plants, bigger yields. Grain Yield also tracks closely with the Number of Pods per Plant (r = 0.96***) and Plant Height (r = 0.94***). For this crop, that means if you breed for taller plants with more vegetative biomass, you'll get more pods and a better final grain yield. Traits like Plant Height, Leaf Area, and Branch Number are tightly intertwined as well. Leaf Area and Leaf Area Index even show a perfect correlation (r = 1.00***), which isn't surprising since LAI is calculated directly from LA. Basically, they're telling us the same thing about canopy cover. Branch Number stands out as a key connecting trait. It's strongly correlated with both Plant Height and Grain Yield (r = 0.93*** for each). So, taller plants tend to branch more, which means more sites for pods. This is backed up by a strong link between BN and NPPP (r = 0.95***).Looking at yield components, Number of Pods per Plant seems to have the biggest impact on yield more than pod size or seed weight. Average Pod Length and Number of Seeds per Pod both show positive correlations with Grain Yield (r = 0.74*** and r = 0.84***), but they aren't as influential as NPPP. It's also interesting that number of pod per plant and NSPP go hand in hand (r = 0.85***), Thousand Seed weight shows the weakest connections to the other traits, though they're still statistically significant. Its link to Grain yield is moderate (r = 0.53***), and it's lowest with Biomass at r = 0.50***. This tells us that seed weight isn't as closely tied to vegetative growth as seed number is. Finally, the Harvest Index which measures how efficiently the plant turns biomass into grain shows a strong positive correlation with Grain Yield (r = 0.74***), but a weaker one with TSW (r = 0.48***). So, in this crop, physiological efficiency is driven more by how many seeds the plant makes

Table 19 : Correlation between growth, yield components, and yield

	PH	LA	LAI	PBN	APL	NPPP	NSPP	ADBY	GY	TSW	HI
PH	1										
LA	0.88***	1									
LAI	0.88***	1.00***	1								
BN	0.93***	0.84***	0.84***	1							
APL	0.77***	0.71***	0.71***	0.76***	1						
NPPP	0.94***	0.82***	0.82***	0.95***	0.76***	1					
NSPP	0.84***	0.75***	0.75***	0.83***	0.83***	0.85***	1				
ADBY	0.93***	0.82***	0.82***	0.92***	0.73***	0.95***	0.84***	1			
GY	0.94***	0.83***	0.83***	0.93***	0.74***	0.96***	0.84***	0.99***	1		
TSW	0.57***	0.62***	0.62***	0.60***	0.62***	0.55***	0.53***	0.50***	0.53***	1	
HI	0.72***	0.62***	0.62***	0.68***	0.60***	0.69***	0.65***	0.64***	0.74***	0.48***	1

LA= leaf area, LAL= leaf area index, PBN= primary branch number, PL= pod length, NPPP= number of pod per plant, NSPP= number of seed per pod, ADBY= above ground biomass yield, GY= grain yield, TSW= thousand seed weight, HI= harvest index

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4.7. Partial Budget Analysis

The partial budget analysis was done by using the CIMMYT method to determine nitrogen and phosphorus fertilizer rates are most cost-effective for farmers, both grain and straw yields was down adjusted by 10% to get adjusted figures, reflecting the reality that on-farm yields are typically lower than those in carefully controlled experiments. The analysis focused on the key economic indicators: total variable cost (TVC), gross field benefits (GFB), net benefit (NB), and marginal rate of return (MRR), all reported in Ethiopian Birr (ETB).

As expected, the control treatment (no fertilizer) had zero cost and gave the lowest returns: both gross field benefit and net benefit were 76,163 ETB. Increasing N and P rates raised costs more fertilizer meant a higher bill. The most expensive treatment (30 kg/ha N and 92 kg/ha P_2O_5) resulted in a TVC of 24,450 ETB, but it also produced the highest returns: 238,255 ETB in gross field benefit and 213,805 ETB in net benefit. Clearly, applying more fertilizer led to substantially higher profits. Before calculating marginal rates of return, excluded dominated treatments. A treatment is considered dominated if it has a higher cost but a lower net benefit than another option. Several treatments were eliminated this way such as applying only low or moderate rates of phosphorus, or some mid-level combinations like 20 N / 23 P_2O_5 as they were not financially sensible; better returns could be achieved with less investment.

Once the dominated treatments were removed calculated the MRR for the remaining options in farm economics, an MRR of 100% is usually the benchmark farmers want to double their investment before adopting a new practice. The results showed that some investments yielded very high returns. For instance, moving from no fertilizer to 10 kg/ha N (with no P) gave a remarkable MRR of 1250%. The highest MRR in the study 1705.4% came from switching to 30 kg/ha N and 46 kg/ha P_2O_5. Ultimately, the goal is to identify the fertilizer rate that maximizes income without overextending the farmer's investment. The highest rate tested (30 kg/ha N and 92 kg/ha P_2O_5) provided the greatest net benefit: 213,805 ETB. Moving up to this rate resulted in an MRR of 237.6%, meaning that for every extra Birr spent, the farmer gained the original investment plus an additional 2.37 Birr in profit. Therefore, if the aim is maximum economic return, the best recommendation for farmers in this study is to use 30 kg/ha N and 92 kg/ha P_2O_5.

Table 20: Partial budget analysis

N	P	GY (Kg/ha)	AGY (Kg/ha)	SY (t/ha)	ASY (t/ha)	TVC (ETB)	GFB (ETB)	NB (ETB)	MRR (%)
0	0	552.2	497	1.5	1.3	0	76163	76163	_
10	0	766.8	690.1	1.9	1.7	2150	105182	103032	1250
20	0	791.1	712	1.9	1.7	3900	108375	104475	82
0	23	632.6	569.4	1.6	1.4	5100	86898	81798	D
30	0	965.8	869.3	2.2	2	5650	131660	126010	1230.6
10	23	1149.9	987.6	2.6	2.3	6950	149758	142808	1292.2
20	23	869.7	782.7	2.1	1.9	8700	118902	110202	D
0	46	750.2	675.2	1.7	1.6	9800	102402	92602	D
30	23	1136.3	1022.7	2.6	2.3	10450	154732	144282	42.1
10	46	1188.1	1069.3	2.7	2.4	11650	161767	150117	486
20	46	1259.2	1133.3	2.5	2.3	13400	170024	156624	372
0	69	859.4	773.5	1.9	1.7	14500	116895	102395	D
30	46	1487.4	1338.6	3.2	2.8	15150	201618	186468	1705.4
10	69	1236.9	1113.2	2.8	2.6	16350	168602	152252	D
20	69	1511.7	1360.5	2.9	2.6	18100	203476	185376	D
0	92	1123.7	1011.3	2.4	2.1	19200	152310	133110	D
30	69	1643.1	1478.8	3.5	3.1	19850	222726	202876	349.1
10	92	1371.6	1234.5	3	2.7	21050	186516	165466	D
20	92	1594.5	1435.1	3.1	2.8	22800	214839	192039	D
30	92	1755.7	1580.1	3.8	3.4	24450	238255	213805	237.6

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The present study indicate that the main effect nitrogen and phosphorus fertilizer rates significantly influenced days to 50% flowering, days to 90% physiological maturity, plant height, number of primary branches, leaf area, leaf area index, numbers of effective nodules, nodule fresh weight, number of pods per plant, pod length, number of seeds per pod, thousand seed weight, aboveground dry biomass, seed yield, and harvest index. The interaction of nitrogen and phosphorous fertilizer rates significantly influenced plant height, number of primary branch, leaf area, and leaf area index, number of nodules, number of effective nodules, and number of pod per plant and seed yield. The highest seed yield (1755.7 kg ha^{-1}) was obtained from the interaction between 30 kg N/ha and 92 kg P_2O_5/ha. According to the partial budget analysis, the highest net return (213,805 ETB) with acceptable marginal rate return (238%) was obtained from 30 kg N/ha and 92 kg P_2O_5/ha. This indicate that the grower on the study area can received additional benefit of 2.38 ETB for every 1 ETB expense by growing mung bean N-26 variety with the application of 30 kg N/ha and 92 kg P_2O_5/ha.

5.2. RECOMMENDATION

Based on the results of this finding, application of 30 kg N/ha and 92 kg P_2O_5/ha produced highest agronomic yield as well as economic benefit for mung bean (N-26 variety). Hence, it is recommended for the study area and similar agroecologies. However, the current study was carried out only in one location for one cropping season; thus, the result of the present study need to be evaluated and reconfirmed with different agro-ecologies and seasons in order to reach to a conclusive recommendation.

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7. APPENDIXES

Table 1: Mean square of ANOVA for Phonological Parameters of Mung bean crop

Source of Variation	Df	DE	DF	DM
Rep	2	0.017^{ns}	0.05^{ns}	2.52**
N	3	0.067^{ns}	113.79***	46.46***
P	4	0.517^{ns}	5.03***	33.03***
N x P	12	0.372^{ns}	4.78***	8.11***
Residuals	38	0.63	0.31	0.43
CV (%)		-	1.22	0.89
HSD		-	1.74	2.03

Table 2: Mean square of ANOVA for Growth and Nodulation Parameters Mung bean crop

SV	Df	PH	LA	LAI	BN	TNN	ENN	NFW	NDW
Rep	2	10.28*	44240*	0.28*	0.40*	25.03***	19.29***	0.010***	1.7ns
N	3	771.53***	4841422***	30.26***	38.56***	1857.6***	1366.2***	0.232***	0.005***
P	4	671.36***	1009640***	6.31***	34.46***	154.41***	163.37***	0.022***	0.0004***
N x P	12	7.26**	77178***	0.48***	1.14***	16.96***	25.89***	0.001ns	3.0e-5*
Res	38	2.32	9377	0.06	0.12	1.29	1.43	0.001	1.0e-5
CV (%)		3.55	5.18	5.18	7.08	5.86	7.52	11.27	10.44
HSD		4.73	300.56	0.75	1.07	3.52	3.71	ns	0.010

Table 3: Mean square of ANOVA for Yield and Yield-related Parameters of Mungbean crop

SV	Df	APL	NPPP	NSPP	ADBY	GY	TSW	HI
Rep	2	0.56ns	5.28**	1.57*	3.27e5***	31470***	21.37**	6.50**
N	3	6.81***	451.88***	13.22***	8.63e6***	987112***	24.72***	15.62***
P	4	9.90***	413.97***	27.49***	6.73e6***	926041***	11.10*	24.73***
N x P	12	0.82***	15.91***	0.29ns	2.39e5***	38156***	0.72ns	3.50***
Residuals	38	0.19	0.77	0.35	1.74e4	1652	2.92	0.88
CV (%)		4.09	5.13	5.32	3.63	3.59	3.42	3.03
HSD		1.34	2.73	ns	613.70	126.15	ns	8.50