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Response of Haricot Bean (Phaseolus Vulgaris L.) To Inter Row Spacing Andblendednpsfertilizerrateinhuletejuensiedistrict,N Western Ethiopia

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BAHIRDARUNIVERSITY

COLLEGEOFAGRICULTUREANDENVIRONMENTALSCIENCES

GRADUATE PROGRAM

RESPONSE OF HARICOT BEAN (*Phaseolus vulgaris* L.) TO INTER ROW SPACING ANDBLENDEDNPSFERTILIZERRATEINHULETEJUENSIEDISTRICT,NORTH WESTERN ETHIOPIA

M.Sc.Thesis

BY

ZelalemGedefaw Kassa

June2024

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MSc.Thesis

By

Zelalem Gedefaw Kassa

SUBMITTEDINPARTIALFULFILLMENTOFTHEREQUIREMENTSFORTHE DEGREE OF MASTER OF SCIENCES (MSc.) IN “AGRONOMY”

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THESISAPPROVALSHEET

As member of the board of examiners of the master of sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by **Mr. Zelalem Gedefaw Kassa** entitled '**Response of Haricot Bean (*Phaseolus vulgaris* L.) to Inter Row Spacing and Blended NPS Fertilizer Rate at Hulet Eju Ensie District, North Western Ethiopia.**" We here by certify that, the thesis is accepted for fulfilling the requirements for the award of the Degree of Master of Sciences (M.Sc.) in Agronomy.

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DECLARATION

This is to certify that this thesis entitled '**Response of Haricot Bean (*Phaseolus vulgaris* L.) to Inter Row Spacing and Blended NPS Fertilizer Rate at Hulet Eju Ensie District, North Western Ethiopia."** Submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in **"Agronomy"** to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by **Mr. Zelalem Gedefaw Kassa, Id. No. CAES/BDU1401958** is an authentic work carried out by him under our guidance. The matter embodied in this thesis work has not been submitted earlier for award of any degree or diploma to the best of our knowledge and belief.

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DEDICATION

Thisthesisisdedicatedtomyparentsfortheirrelentlesshardworkandinspirationformy success

ABBREVATIONSANDACRONYMS

AARC	AdetAgriculturalResearch Center
ANOVA	AnalysisofVariance
CIMMYT	CentroInternationaldeMejioramientodeMaiz y Trigo
CSA	CentralStatistical Agency
DMRT	Duncan’sMultipleRangeTest
EIAR	EthiopianInstituteOfAgricultural Research
GLM	GeneralLinear Model
LAC	LatinAmericanCaribbean
LAI	LeafAreaIndex
LSD	LeastSignificant Difference
PH	Potential ofHydrogen
RCBD	RandomizedCompleteBlockDesign
SAS	StatisticalAnalysisSystem

ResponseofHaricotBean(*PhaseolusVulgaris*L.)toInterRowSpacingandBlendedNPS Fertilizer Rate at Hulet Eju Ensie District, North Western Ethiopia

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ABSTRACT

Haricot bean (Phaseolus vulgaris L.)is oneof the most important food and export pulse crop in Ethiopia. However, Low soil fertility and inappropriate plant spacing are the production constraints of common bean in the study area. Hence, a field experiment was carried out in Hulet Eju Enesie District, North Western Ethiopia during 2022/2023 cropping season to evaluate the effect of inter-row spacing and blended NPS fertilizer rate on the yield and yield components of haricot bean. The treatments consisted of factorial combinations of four rates of blended NPS (61, 121, 182 and 243 kg ha^{-1}) and three inter row spacing of haricot bean (30,40, 50 cm). The treatments were arranged in Randomized Complete Block Design with three replications. The treatments were arranged in Randomized Complete Block Design with three replications. Data on phenological, growth and yield parameters of the tested crop were collected and analyzed using SAS-JMP-16 software. Results revealed that all phenological parameters of the tested crop were not significantly influenced by both the main and interaction effects of inter-row spacing and blended NPS fertilizer rates

The interaction effect of inter-row spacing and blended NPS fertilizer rate had a significant effect on plant height, number of branch per plant, number of pod per plant, number of seed per pod, above ground dry biomass yield and grain yield. The highest number of pod per plant (18.40), number of seed per pod (8.23), above ground dry biomass (6.10t ha^{-1}) and grain yield(4.59t ha-1) were recorded from a combined application of 40cm inter-row spacing with 182kg ha^{-1} of blended NPS fertilizer rate. Indeed, according to the partial budget analysis,40cm inter-row spacing with combined application of 182kg ha $^{-1}$ gave the highest net benefit (119846) with acceptable marginal rate of return 5173%. Thus, it can be concluded that the combined application of 40cm inter-row spacing with 182kg ha^{-1} of blended NPS fertilizer rate would be recommended for maximum production and profitability in the study area and areas withsimilaragro-ecology.Thisresearchalsosuggested furtherresearchonthe variousratesof *combinedapplicationsofVermicompostingandofinorganicfertilizeracrossvariousagro ecology and years.*

Keywords:*BlendedNPS fertilizer,inter-rowspacing,grainyield,haricotbean.*

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CHAPTER1.INTRODUCTION

BackgroundandJustification

I**ntroduction:** Haricot beans (Phaseolus vulgaris L.) play a vital role in the agricultural landscape of Ethiopia, contributing significantly to food security and income generation. Understanding the optimal agricultural practices that enhance haricot bean production is crucial for sustainable farming in the region. In this context, exploring the response of haricot beans to inter-row spacing and blended NPS fertilizer rates can provide valuable insights for farmers in the Hulet Eju Ensie district, located in North Western Ethiopia.

Background: Haricot beans are a staple crop in Ethiopia, known for their nutritional value and economic importance (Gebremdhin Teklu, 2016). In East Africa, haricot beans are grown by small-scale farmers, often cultivated in unsuitable conditions with minimal inputs (Buru Adugna, 2019). In Ethiopia, haricot beans are one of the most important cash crops and acrucial source of protein for farmers (El-Dahshouri *et al.*, 2017). According to the CSA (2021) report,theAmhararegionhas81.19%(10,538,341.91hectares)ofmajorcerealcropgrowthand 12.90% (1,674,950.34 hectares) of pulse crop growth. From these, approximately 0.54% (about 1,855,340.69 quintals) and 1.07% (3,670,300.05 quintals) are haricot beans (white) and haricot beans (red), respectively. The national total area of haricot bean production is estimated at 1,855,340.69 white haricot beans and 3,670,300.05 red haricot beans produced in quintals, with yields of about 17.96 and 17.62 quintals/ha for white and red haricot beans, respectively (CSA, 2021).

According to this report, the current national average yield of haricot beans is 1.779 tons/ha. However, this yield is far less than the attainable yield (2.5–3.6 tons/ha) due to poor agronomic practices such as inter-row, intra-row spacing and inappropriate fertilizer rates, underuse of fertilizers which are major constraints in haricot bean production. The fertility of mostEthiopian soils has already declined and continues to decline, posing another challenge to haricot bean crop production (Halie Wasie; Boke Shiferaw Boke *et al.*, 2009). The Hulet Eju Ensiedistrict,withitsuniqueagro-ecologicalconditions,presentsanopportunitytoinvestigate howinter-rowspacingandblendedNPSfertilizerratesinfluencethegrowthand yieldofharicot beans.

Previous studies have shown that proper spacing between rows can optimize light interception, air circulation, and water utilization, ultimately affecting plant growth and development. Additionally, the application of blended NPS fertilizers can enhance soil fertility and nutrient availability, which are essential for maximizing haricot bean productivity (Shumi Delnesa,2018;TuluAwulia,2020). Forinstance,research conductedinsimilarregionshasdemonstrated that wider inter-row spacing combined with appropriate fertilizer rates can lead to improved plant growth, higher pod yield, and better nutrient uptake efficiency in haricot beans. By assessing the response of haricot beans to different inter-row spacing configurations andblended NPS fertilizer rates in the context of the Hulet Eju Ensie district, this study aims to provide practical recommendations that can help farmers optimize their agricultural practices and increase haricot bean productivity sustainably.

.StatementofProblem

Haricot bean (Phaseolus vulgaris L.) is a significant legume crop in Ethiopia, contributing to both food security and the agricultural economy. However, the productivity of haricot bean in the Hulet Eju Enesie District of North Western Ethiopia remains suboptimal due to various agronomic challenges. Among these challenges, the appropriate inter-row spacing and the optimalrateofblendedNPS(Nitrogen,Phosphorus,andSulfur)fertilizerapplicationarecritical factors that influence the growth, yield, and overall performance of the crop (Deresa Shumi *et al*., 2018).

Despite the known importance of these agronomic practices, there is limited research and empirical data specific to the local conditions of the Hulet Eju Enesie District. This lack of localized information hinders farmers from making informed decisions that could enhance their crop productivity. Therefore, this research aims to investigate the response of haricot bean to different inter-row spacings and rates of blended NPS fertilizer application in this specific region.Thefindingsareexpectedtoprovideactionableinsightsandrecommendationsthatcan helpimproveharicotbeanyields,therebycontributingtobetterfoodsecurityandeconomic outcomes for local farmers.

Objectivesof theStudy

Generalobjective:

- To evaluate the response of haricot bean (Phaseolus vulgaris L.) to different inter-row spacing and blended NPS fertilizer rates for improved productivity under improving agronomic practice in Hulet Eju Ensie District of North Western Ethiopia.

Specificobjectives

- Todeterminetheoptimuminter-rowspacingformaximizingthegrowth,yield,and yield components of haricot bean under.
- ToassesstheeffectofdifferentblendedNPSfertilizerrateson thegrowth,yield,and yield components of haricot bean under.
- Toevaluatetheinteraction effect of inter-rowspacingand blended NPS fertilizerrateon the growth, yield, and yield components of haricot bean under.
- To identify the most economically viable combination of inter-row spacing and blended NPS fertilizer rate for haricot bean production in the study area.

CHAPTER2.LETERATURE REVIEW

Descriptionof HaricotBean

Haricot bean (Phaseolus vulgaris L), locally known as 'Boleqe', is also referred to as dry bean, common bean, kidney bean, and field bean (Daniel Tadesse *et al*., 2012). Being a self-pollinating leguminous crop in the family Fabaceae, haricot bean exhibits two growth habits: determinate (bush) and indeterminate (vining or trailing) growth habits (Helm *et al*., 1990).

The haricot bean, characterized by a pronounced tap-root that rapidly grows to a depth of one meter, also possesses extensive lateral roots primarily concentrated in the top 15-20cm of the soil. Its central stem and branches support alternate trifoliate leaves that are somewhat hairy. Stem surfaces are also hairy, while the flowers are small, and the pods measure 10-20 cm in length, appearing straight or curved (Katungi *et al*., 2009). This crop is a short-day plant, favored bysmall-scale farmers for its short growth cycle, typicallyaround 70 days, allowing for production even in regions with erratic rainfall patterns. It is classified as a warm-season crop (Rana *et al*., 2017).

Origin andDistributionofHaricot Bean

The common bean originated in Central and South America, where it was cultivated as early as 6000 BC in Peruand 5000 BC in Mexico.TheSpaniards and thePortugueseintroduced it to the Old World. It is now widely cultivated as a major food crop in many tropical, sub-tropical, and temperate areas of the Americas, Europe, Africa, and Asia (Bilisuma Tolasa *et al*., 2019).Globalharicotbeanproductionisestimatedtobeabout23.6milliontons,withanaverageof 53.7 million hectares (FAOSTAT, 2014), making it the most widely utilized legume crop. The top five leading common bean-producing countries are Myanmar, India, Brazil, China, and Mexico, accounting for more than 50% of the total production (FAOSTAT, 2014). The wild ancestor of the haricot bean is native to Central and South America, and it was domesticated independently in both Mexico and Peru. Domestication occurred over 5,000 years ago, and cultivation had spread throughout the Americas before the arrival of Europeans in the 16th century. Haricot beans originated from Latin America and have two primarycenters of origin in the Mesoamerican and Andean regions, easily distinguished by molecular means (Blair *et al*., 2006).

The common bean (*Phaseolus vulgaris* L.) is one of the most important legume crops grown on all continents of the world due to its high protein content. It serves as a vital source of protein and energyin human diets, particularlyin tropical and subtropical developingcountries, such as those in the Americas, Eastern and Southern Africa (Walelign Worku, 2002). Haricot bean cultivation occurs in a variety of crop systems and environments across regions as diverse as Latin America, Africa, the Middle East, China, Europe, the United States, and Canada. Latin America leads in both bean production and consumption, where beans hold traditional and significant foodvalue, especiallyin Brazil,Mexico,theAndean Zone, CentralAmerica, and the Caribbean. In Africa, beans are primarily grown for subsistence, with the Great Lakes region boastingthehighestpercapitaconsumptionglobally. InEthiopia,haricotbeancultivationlikely began with the Portuguese introduction in the 16th century (Bezaweletaw, Kebre *et al*., 2006). Haricot bean production in Ethiopia spans almost all regional states, with varying intensities. However, production is concentrated in two regions: Oromia and the Southern Nations, Nationalities, and Peoples Region (SNNPR), which collectively contribute about 85 percent of the total national production. The remaining 15 percent comes from regions including Afar, Amhara, Tigray, Somali, Gambella, and Benishangul-Gumuz (Alemu Dawit and Bekele Adam, 2005).

EnvironmentalRequirementsofHaricotBean

Haricot beans can be widely grown in lowland and mid-altitude areas, adapting well to elevations ranging from 1400 to 2000 meters above sea level (Beebe *et al*., 2011; Daniel Tadesse *et al*., 2012). Certain regions, spanning from 500 to 1900 meters, are suitable for cultivation when rainfall ranges from 500 to 1500 millimeters throughout the growing season (Alemu Habtamu, 2017; Bilisuma Tolasa, 2019). Optimal growing conditions include a rainfall range of 350–500 mm during the growing season, coupled with low relative humidity tomitigate the risk of bacterial and fungal diseases. While it does not require excessive moisture, haricot beans are not drought-resistant, and depending on soil and climatic factors, they necessitate 300–600 mm of rainfall per year (Cherinet Zeleke, 2008). In Ethiopia, they can be cultivated in areas with elevations between 1000 and 2000 meters above sea level, receiving annualrainfallof500to1100mm,withapproximately300to400mmofwaterrequiredduring the growth period. Haricot beans are susceptible to both water scarcity and excess moisture (Walelign Worku, 2015).

It is well adapted to get an optimum temperature range of 16–24 °C and a frost-free period of 105–120 days (Alemu Habtamu *et al.,* 2017). It is considered more sensitive to high temperatures than other legume crops, whereby daily temperatures greater than 300 °C andnighttemperaturesgreaterthan200°Ccauseasignificantreductioninyieldbyinhibitingpollen growth (Pal *et al*., 2014). Common bean grows well at temperatures ranging from 15 to 27°C and will withstand temperatures up to 29.5°C. High temperatures (close to or higher than 35°C) and moisture stress during flower and pod setting result in the abortion of large numbers of blossoms and developing pods. It required deep, friable, and well-aerated soil types with an optimum pH range of 6.0 to 6.8 (Ojiem, J.O. *et al*., 2018). The crop is adapted to a wide rangeof climatic conditions, ranging from sea level to nearly 3000 meters above sea level (m.a.s.l.), depending on variety selection. However, it does not grow well below 600 meters due to poor pod set caused by high temperatures (Gebre-Egziabher Murut, 2014). Haricot beans can be successfullygrowninnon-acidicandwell-drainedsoils.Ideally,thesoilpHshouldbebetween 6.5 and 7.5. ThepH should not bebelow 5.0 orabove8.0.

ImportanceandUtilizationof Haricot Bean

Haricot beans are one of the most important pulses crops in the world. Pulses, including haricot beans, contribute approximately 21 million tons of nitrogen annually through their symbiotic relationship with nitrogen-fixing soil bacteria, enriching the soil (Kinjal *et al*., 2021). In Ethiopia, haricot beans are highlyfavored byfarmers due to their earlymaturityand serve as an emergency crop during times of crop failure (Legesse *et al*., 2006; Shiferaw G. *et al*., 2020; BelachewKiflemariam*etal*.,2022).Theyarecrucialmarketcropsand aprimaryprotein source for farmers in many lowland and mid-altitude zones. Haricot beans also play a vital role in supplementing protein in the cereal-based Ethiopian diet and contribute significantly to the country's export earnings, serving as a notable commodity for foreign currency generation. Besides, common beans offer health benefits due to their rich protein content (approximately 23% for dried shelled beans and 6% for green beans) and serve as a valuable source of iron and zinc, essential elements for mental development (Solomon Bekele and Firew Mekbib, 2019). Ethiopia'sexportincomefrompulses,primarilyharicotbeans,surpassesthatofotherpulses such as lentils, faba beans, and chickpeas, comprising over 85% of the country's total export earnings (Negash, 2007).

Haricot bean in Ethiopia is produced in almost all the regional states with varying intensity (Kueneman *et al*., 2008).The national total area of common bean production was estimated at 290202.43 ha of land, from which about 483922.65 tons were produced per year (CSA, 2017). Two types of common bean are grown: the canning type, mostly grown for export markets, dominates the Oromia region (Northeast Rift Valley), and the cooking type is primarily grown for food in the Southern Nations Nationality Peoples Region. Significant amounts of thecooking kind are exported to the bordering countries, predominantly Kenya (Ferris andKaganzi, 2008). Haricot bean has been grown for export in Ethiopia for over 40 years, and it ranks third as an export commodity in Ethiopia, contributing about 9.5% of total export value from agriculture (FAOSTAT, 2010). Haricot bean production was capable of recovering and even exceeding its production and export volumes in the late 1970s and early1980s (Katungi *et al*., 2010).

TrendofHaricotBeanProduction

Haricot bean is the most important food legume in the world used for direct human consumption. Average per capita consumption of haricot bean in the top bean production areas is highly concentrated in Africa, estimated at 31.4 kg/year (Sanyang and Tankou, 2016). The crop occupies more than 3.5 million hectares in sub-Saharan Africa, accounting for about 25% of global production, but production is concentrated in the densely populated areas of East Africa. The Crop Production Survey indicates that a total cropland area of about 1,674,950.34 hectaresiscoveredbypulses,fromwhichatotalvolumeofabout31,999,988.65quintalsand 9.36grainsareobtainedfromprivatepeasantholdings.Fromtheseharicotbeans(white),0.80% (about 103,288.55 hectares) and haricot beans (red), 1.60% (about 208,295.03 hectares) yields was obtained (CSA,2013). Accordingto ATA (2018),theagriculture-leadingsectorcontributes to nearly 34% of the country's gross domestic product (GDP) and 71% of employment. Crop production makes up 72% of the total agricultural GDP, of which cereal production covers 79.9%, pulses 13.2%, and oil seeds 6.9%. But the national average yield of haricot beans in Ethiopia is 1.69 t/ha (CSA, 2016) which is low as compared to the yield (2.5–3.6 t/ha) achieved at research centers. The crop is cultivated in different parts, mainly Oromia, Amhara, and the Southern Nations Nationalities and Peoples Region (SNNPR). Their share of the national common bean production is 51% for Oromia, 24% for Amhara, and 21% for SNNPR (CSA, 2018). Almost all haricot beans are produced under rain-fed conditions by smallholder farmers on less than 0.5 hectares (Miruts Fistum *et al*., 2013).

HaricotBeanProductionin Ethiopia

Haricot bean is a subsistence crop in traditional farming in Ethiopia. Almost all haricot bean production (more than 99 percent) comes from five major producing regions: Oromia, Amhara, Southern Nations Nationalities and Peoples Region State (SNNPRS), Benishangul-Gumuz, and Tigray. In all parts of Ethiopia, the crop is grown by subsistence farmers as a sole crop and intercropped with either cereal maize or sorghum (Belachew Kiflemariam *et al*., 2022). In addition to sole cropping, haricot beans can be grown under intercropping because of their suitable growth characteristics. It is vital to choose appropriate varieties that are suitable for the selected cropping system (Maguje Masa *et al*., 2017). In the major common bean-producing areasofEthiopia,productionisgenerallytrendingupward.Bothareaandyieldhavebeen growing at a positive average rate since 2002 in response to the economic reforms of the 1990s. However, the national average yield is still low. This yield gap is caused by numerous production constraints, including declining soil fertility, rainfall variability, pest pressure, poor agronomic practices, and poor accessibility to good soil (Daniel Tadesse *et al*., 2014).

HaricotbeanproductionpotentialinEthiopia

The world's largest producers of haricot beans are India, Myanmar, Brazil, and America, respectively. In East Africa, haricot beans are grown twice a year, with the sowing season runningfrom March to April and from September to October, except in parts ofEthiopia,where the main growing season is from June to August. The largest producers of haricot beans in Africa are Kenya, Uganda, Tanzania, and Ethiopia, which rank 9. Haricot bean is an important pulse crop in Ethiopia and around the world. It is the second-most productive bean, next to the faba bean. Currently, haricot bean production takes place to a varying degree in all regions of the low and mid-altitude agro-ecologies of the country. According to Abele Wogayehu and Tewodros Tefera's (2015)study, the current Haricot bean productivityper hectareis verylow in Ethiopia. Improved haricot bean production encompasses the proper use of different agronomic practices, which include improved variety, seed rate, spacing, fertilizer rate, and pesticide application as per recommendation (Shumi Deresa, 2018). However, the current national average yield of common bean (1485 kg ha-1) is far less than the attainable yield (2500–3000kg ha-1) under good management conditions for most improved varieties.

Haricotbeanproduction challengeinEthiopia

According to Wogayehu Abele and Tewodros Tefera (2015), one of the major constraints is spacing, implying that as there is a unit increase in quantityof seed, production will increase by 29% up to the point where applying population density of seed reaches its optimum level. Witha decrease in the amount of seed application per hectare of land, the level of production decreases by 29%. One of the major constraints on haricot bean production is the unavailability of soil nutrients, the inappropriate amount of fertilizer, and inappropriate spacing. The drive for higher agricultural production without the balanced use of fertilizers created problems of soil fertilityexhaustion.InEthiopia,thelow yieldofharicotbeansisattributedtoseveralproduction constraints,whichinclude alackpooragronomicpracticessuchunappropriate row spacingand un appropriate fertilizer rate (Masa Adugna ., 2017). There is a low emphasis on haricot beans by concerned bodies in terms of training, input provision, and follow-up as compared to cereals (Katungi *et al.*, 2009).

Ethiopian farmers, in general, use lower seed rates than research recommendations, resulting in lower grain yields (Walegwa *et al*., 2002). Environmental factors, such as low soil nitrogen and phosphorus levels, and acidic soil conditions, are important constraints for bean production in most areas where the crop is grown (Molden David *et al*., 2010). Wortmann (2006) alsoreported that the low soil fertility status, especially low levels of nitrogen and phosphorus, are majorconstraintsforcommonbeanproduction,responsibleforthelossofgrainyieldsofupto 1.2 million tons in Africa. In Ethiopia,haricot bean production takes place to varyingdegrees in all regions of the low and mid-altitude agro- ecologies of the country. However, almost all haricot bean production (more than 99 percent) of the country comes from five main haricot bean production regions: Oromia, Southern Nations Nationalities and Peoples Regional State (SNNPRS),Amhara,BenishangulGumuz,andTigray(WogayehuAbeleandTewodrosTefera., 2015).

EffectofPlantSpacingonLegume Crops

Plant population density is a crucial factor influencing crop yield. The yield of a plant is influenced by competition within and outside the plant, as well as environmental factors. Maximum yield is achieved when competition is minimized. Excessive planting density can hinder light penetration into the canopy and increase competition among plants. Therefore, identifyingthe appropriateplanting densityis essential for achieving high yields (AgajieMelak, 2014). The arrangement of plants in a unit area plays a significant role in resource utilization, including light, nutrients, and water. It also affects the rate and extent of vegetative growth, as well as the development of diseases and pests (Shirtliffe Steven and Adrian Johnston, 2002). Research by Reinhard *et al*. (2019) demonstrated that varieties with the strongest lodging tendencies resulted in higher crop stands, while the highest seeding rates led to increased lodging and reduced crop stand height, especially with wider row spacing. Plant population density also influences early ground cover, the competitive ability of crops, soil surface evaporation, and light Interception (Shallamo, 2023).

Planting spacing significantly affects the growth and development of legumes. Closer spacing canenhancediseasedevelopmentandresultinlower yieldsforlegumes(MohammadZakaria *et al*., 2020). According to Tamiru Tatek *et al.* (2020), the seed yield of haricot beans increases as the plant population increases (narrow spacing). However, a high plant population can lead to reduced aeration, increased humidity, and prolonged periods of dampness. Optimal plantdensityshould aim to maximize yield whileminimizingseed costs. In Ethiopia, arecommended spacing of 40 cm x 10 cm has been adopted as standard, regardless of growing conditions and locations, without clear consideration of planting density studies (Tamiru Tatek *et al*., 2020). However, many farmers are uncertain about the appropriate planting density to use (Muchira *et al*., 2018).

EffectofInterRowSpacingonHaricot Bean

According to Mohammad Zakaria (2020), under a 40×15cm spacing condition, peas required a minimum number of days for the first flowering. Wider spacing options (40×15cm, 40×10cm, and 30×15cm) provided adequate space and reduced biotic and abiotic stresses, leading to a higher trend of branching. Gebremedhin Welu (2013) conducted experiments that revealed stronger and larger stem thickness as plant populations decreased, attributed to slower growth due to reduced intra-specific competition at lower plant densities. Additionally, larger spacing resulted in thicker stems, while closer spacing led to fewer branches compared to wider spacing (El Naim *et al*., 2010). Similarly, Weber *et al.* (1966)foundthat soybean plants grown at higher densities were taller and had fewer branches, consistent with the experiment's observation of increasedbranchnumberswithdecreasingdensity.Stemthickness,ontheotherhand,decreased as population density increased.

Among inter-row spacing options, narrow spacing of 30 cm required more days to reach physiological maturity compared to wider spacing options of both 40 cm and 50 cm (Maguje Masa*etal*.,2015).Thisphenomenonmaybeattributedtothehigheramountofradiationenergy absorbed at wider row spacing, which can disrupt the activity of growth-regulating hormones in the plant's cell-differentiating parts, ultimatelyhalting further growth increments and prompting earlier maturation. Shiferaw (2013) similarly observed an increase in days to maturity as inter-row spacing widened from 20 to 30 and 40 cm in check pea.

Inter-row spacing demonstrated a significant effect on both the number of total pods per plant and the number of seeds per plant. Wider inter-row spacing (60 cm) resulted in the highest number of total pods per plant, while the lowest number of pods per plant was recorded for narrow inter-row spacing (30 cm) (Deresa Shumi *et al*., 2018). In contrast, Esubalew Getachew (2014) found that spacing plants at 40 cm by 7 cm resulted in the highest total pod yield, whereas the lowest total pod yield was observed for green beans spaced at 40 cm by 10 cm.This difference in total pod yield, amounting to 49.43 percent between the maximum and minimum, may be attributed to the larger number of plants per unit area under narrowerspacing, which restricted unnecessary vegetative growth and favored pod setting. Additionally, in faba beans, the number of pods per plant increased with increasing plant spacing from 20 cm to 30 cm. This increase may be due to a higher net assimilation rate and a reduction in competition in wider spacing, leading to more pods per node (Abdel Latif, 2008).

AccordingtoEsubalew Getachew(2014),the yieldofharicotbeansincreasedatnarrowspacing compared to wider spacing. Higher planting densities of haricot beans resulted in higher pod yields per unit area compared to lower planting densities. Achieving appropriate plant populations through different planting patterns is crucial for increasing both product and productivity. Planting patterns influence sunlight radiation interception and the utilization of moisture from the soil (Musana *et al*., 2020). Additionally, row spacing plays a role in modifying plant architecture, the photosynthetic competence of leaves, and dry matter partitioning in various field crops (Hussain, 2013). However, beyond a certain limit, increasing or decreasing row spacing does not necessarilylead to increased yield. Therefore, optimum row spacing is essential to enablethe plant to achieve its potential yield (Galwab and Kamau, 2017). Planting pattern is important for the distribution and dispersion of light energy quality and quantity among plants, ultimately resulting in increased yield product and biological yield witha higher ratio of nutrient uptake (Masa *et al*., 2017).

Both too narrow and too wide spacing can have negative effects on grain yields due to competition and shading. In the case of excessively wide spacing, yield reduction may occurdue to inefficient utilization of growth factors (Mitiku Woldesenbet, 2012). Conversely, too narrowspacingcanaffectgrainyieldthroughcompetitionfornutrients,moisture,air,radiation, etc. (Gebremedhin Welu, 2015). According to Adamu *et al*. (2008), maintaining optimum plant density under suitable environmental conditions can result in yields of more than ten quintalsper hectare. Similarly, Maguje *et al*. (2017) suggested that the planting pattern of haricot bean cropsdirectlyorindirectlyaffectstheirproduction potential. Inlow-densityplantingsofasingle species, increasing density can lead to higher yields per unit area, but intraspecific competition becomes more intense as more individuals compete for the same limited resources. This increased competition may manifest as a reduction in individual plant performance, such as biomass or grain weight per plant. The number of branches was significantly higher in plants spaced at 30 cm by 15 cm, while the lowest number of branches was observed in plants spaced at 50 cm by 7 cm. This difference could be attributed to lower competition between plants at wider spacing.

OptimumInter-row SpacingforMaximizing HaricotBean Productivity

Optimization of plant density for high yielding genotypes with suitable inter- as well as intra-row spacing is crucial in order to increase haricot bean productivity per unit area (Yacob Alemayehu *etal.*,2015).Cropplantshouldhavetocoverthesoilas earlyaspossibletointercept maximum sunlight to produce high dry matter as the intercepted solar radiation and dry matter production are directly related as plant density increase the amount of dry matter in vegetative part also increases. By maintaining optimum plant population under suitable environment it is possible to get more than ten quintals per hectare (Gebremhdin wulu , 2015).

Selecting optimal row spacing is important to improve crop productivity as plants growing in too wide of a row may not efficiently utilize light, water, and nutrient resources. However,crops grown in too narrow rows may result in severe inter row competition. Row spacing also modifies plant architecture, photosynthetic competence of leaves, and dry matter partitioning in several field crops(Maguje Masa ,2020).Optimum plant density is the minimum population that gives maximum yield and suitable plant arrangement per unit area, allowing crops to exploit resource optimally and produce high yields(Gemechu Ejigu and Solomon Tulu ,2021).

High plant density causes certain modification in the growth of the plants like increase in plant height,reductioninleafthickness,alterationinleaforientations,erectleaf development,narrow and vertically arranged intervals to intercept more sun light (Mitiku Woldesenbet , 2014).

Effectof InorganicFertilizeronLegume Crops

At the national level, only 4.44% of grain and legume crop lands have received inorganic fertilization, which accounts for only 3.4% of the total national fertilizer consumption (CSA, 2016). This clearly justifies the fact that the majority of grain legume production in Ethiopia is still practiced without nutrient application, although research results indicate the need for fertilization. The grain yield of faba bean improved by 55% over the control with theapplication of18/20 kg N/P ha-1 (AbereMnalku, 2020). Improving soil fertilitythrough theuse of inorganic fertilizers can greatlyincrease grain and legume productivity. Fertilizer application increases biomass accumulation at harvest. Nitrogen has been found to promote shoot and leaf growth and is very important for biomass accumulation (Arnold *et al*., 2018). These resultswere similar to those of Odundo *et al*. (2010), who found out that application of 30 kg P/ha increased the dry matter yield of cowpea by up to 74% compared to the control. Inorganic fertilizers have been an important tool to overcome soil fertility problems and are also responsible for a large part of the increase in food production (Buru Adugna, 2019).

Gemechu Ejigu and Solomon Tulu (2021) investigated the effect of increasing the NPSfertilizer rate on the flowering and physiological maturityof crops. Theyfound that higher rates of NPS fertilizer led to delays in both flowering and physiological maturity. For example, the highest number of days to reach 50% flowering was recorded with the application of 150 kg of NPS ha^{-1}, while the shortest duration to flowering days was observed with the application of 50 kg ha-1 of NPS. Similarly, the highest rate of NPS (150 kg ha-1) resulted in the longest time required to reach 90% physiological maturity. These findings highlight the importance of carefully managing fertilizer application rates to optimize crop growth and development while avoiding delays in key growth stages.

Application of inorganic phosphorus fertilizer is a crucial component in reducing yield loss causedbythenutrient.Thisisbecauseanadequateamountofphosphorusnutritionenhances the physiological activities of legume crops, including stimulation of early root formation, growth, nodulation, photosynthesis, and flowering (Tamiru Meleta *et al.*, 2021). Application of fertilizer in the recommended amount is essential for high grain yield and quality (Morgado, 2003). The use of fertilizer is considered to be one of the most important factors in increasing crop yield per unit area; however, the response to the type of fertilizer and rate of application vary widely with location, climate, and soil type (Marshner, 2002). It has been reported that there were increased yield responses of pulse for nitrogen fertilizer (Morgado, 2003). Many studies on legumes indicate that NPS availability in the soil is a great limitation for bean production in the tropics (Morgado, 2003).

The application of fertilizer to haricot bean production varied depending on the area of production and soil fertility according to the regional agricultural bureau extension program manual (2006). Setegne and Leggese (2003) the recommended fertilizer rate will be 100 kgNPS ha-1 and 50 kg UREA ha-1. The crop response to nutrients was affected by soil moisture, temperature, tillage, and the increasing rate of nitrogen, which helped to accumulate more dry matter during late flowering and delay physiological maturity. The role of nitrogen in haricot beans is essential for growth and flowering. Nitrogen is an important component of many important structural, genetic, and metallic compounds in plant cells. It has majorcomponents of chlorophyll; nitrogen is also present as part of nucleon-proteins, amino acids, amnions, sugars, and other organic compounds in plants (Habtu, 1994).

EffectofBlendedNPSFertilizeronHaricotBean

The traditional methods of soil fertility regeneration, such as fallowing and organic fertilizeruse, have become largely ineffective due to land scarcity caused by overpopulation. Additionally, most crop residues are removed by farmers for fuel or construction purposes, and the remaining organic matter is often depleted by livestock grazing on stubble. These practices have led to significant nutrient depletion and low soil fertility levels (Belay Yebo, 2015). Consequently, soil erosion and low fertility exacerbate each other, with topsoil loss amplifying deficiencies in essential nutrients like nitrogen (N) and phosphorus (P), which are primary contributors to soil infertility (Belay Yebo, 2015). To address these issues, increased rates of NPS (nitrogen-phosphorus-sulfur) supply have been proposed. This approach aims to mitigate soil fertility challenges by promoting prolonged vegetative growth through combined applications of nitrogen with phosphorus, sulfur, and boron. Studies by Nuru Seid (2020) suggest that varying NPSB rates significantly affect the timing of key developmental stages in common beans, such as flowering and physiological maturity. Furthermore, research by Deresa Shumi *et al*. (2018) highlights the significant influence of blended NPSB fertilizer on flowering time, physiological maturity, and plant height, underscoring the potential of combined nutrient applications to improve crop performance and soil fertility management.

The Ethiopian Soil Information System project revealed significant deficiencies in various nutrients beyond those provided by diammonium phosphate (DAP) and urea (Arega Abebe and ZenebeMekonnen,2019).Identifyingthemostefficientnutrientsources,particularlynitrogen
(N) and phosphorus (P), is crucial for enhancing common bean productivity (Arega Abebe and Zenebe Mekonnen, 2019). Low soil fertilityremains a major obstacle to sustainable agricultural production and productivity in Ethiopia (Desta Abayechaw and Ermias Ejamo, 2019). To address this challenge, balanced fertilization is essential to maximize productivity (Desta Abayechaw and Ermias Ejamo, 2019). By applying balanced fertilizers, sustainable production can be enhanced, meeting the nutrient requirements of crops based on their physiological needs and expected yields. However, the prevailing fertilizer management program in Ethiopia primarilyfocusesonthe applicationofnitrogen(N)andphosphorus(P)fertilizersintheformof DAPandurea,orblanketrecommendationsformajorfoodcrops.Thisunbalancedapproach,

with a continuous application of N and P fertilizers, ultimately leads to soil fertility depletion (Desta Abayechaw and Ermias Ejamo, 2019).

Soil health can be maintained by sustainable crop production. It has both economic and environmental considerations. An imbalanced fertilizer use results in low fertilizer use efficiency,leadingtolowereconomicreturnsandagreaterthreattotheenvironment.Moreover, recently acquired soil inventory data revealed that deficiencies of most nutrients, such as N, P,S, and B, are widespread in Ethiopian soils. Fertilizers are an efficient exogenous source ofplant nutrients since plant growth and crop production require an adequate and balanced supply of nutrients to maximize productivity by optimizing plant nutrient uptake. Several studies have reported that chemical fertilizers are the major nutrient sources for improving crop productivity (Arega Abebe and Zenebe Mekonnen, 2019). Balanced application of mineral fertilizer was reported to maximize crop yields and reduce N and P losses to the environment; in contrast, chemical fertilizers, specificallyDAP and Urea, were used for major crop production, including haricot bean, over decades in Ethiopia. According to the Ethio-SIS (2016) fertilizer type recommendation map or atlas, eight types of fertilizer blends are identified for southern Ethiopia. Similarly, two types of fertilizers—NPSB—were recommended for Hulet Iju Ensie Woreda. However, there is no detailed investigation in the area to confirm the amounts of fertilizer suitable for haricot bean production.

InteractionEffectofBlendedNPSFertilizerandInterRowSpacingonHaricot Bean

The drive for higher agricultural production without a balanced use of fertilizers created problems of soil fertility exhaustion (Sigaye, 2022). Recently, according to the soil fertilitymap, Ethiopian soil analysis data revealed that deficiencies of most of the nutrients, such as nitrogen (86%), phosphorus (99%), sulfur (92%), and birth (65%), were widespread inEthiopian soils (Ethio-SIS, 2016). To overcome this problem, multi-nutrient-balanced fertilizers containing N, P, and S in blended form have been issued to address site-specific nitrogen deficiencies and thereby increase crop production and productivity. Plant growth and crop production require an adequate and balanced supply of nutrients to maximize productivity by optimizing the plant population density for nutrient uptake. A balanced application of mineral fertilizerandappropriateplantdensitywerereportedtomaximizecropyields(Desta

Abayechaw and Ermias Ejamo, 2019). Applying NPS fertilizer increases crop growth and yield on soils that are naturally low in NPS and in soils that have been depleted.

Application of phosphorus is an essential macronutrient that affects plant growth and yield by promoting root growth and stimulating lateral branching, which increases the plant's ability to absorb nutrients from the soil. Yield and yield-contributing characters of haricot beans were significantly influenced by different levels of nitrogen and phosphorus. The number of flowers (plant 1) and pods (plant 1) significantly increased with increasing levels of nitrogen. Plants treated with 200 kg N ha-1 produced the maximum number of flowers per plant (Kakon *et al*., 2016). Taminew Zewudie (2021) reported an increase in the number of pods per plant with increased levels of NPS fertilization from 0 kg N; 0 kg P2O5 to 36 kg N; 92 kg P2O5 ha-1, and the highest number of pods per plant was obtained from the application of 36 kg N; 92 kg P2O5 ha-1, whereas the lowest number of pods per plant (14.58) was reported from the no fertilizer plot in common bean. Likewise, Abdela *et al*. (2018) also reported that average pod weight for common bean showed a significant increase from 3.64 to 5.59 and 4.31 to 5.45 gram per plot with increasing levels of NP kg ha-1 from 0 to 82 and 0 to 92, respectively. Similarly, Ersa Shumi (2018) reported the highest number of pods per plant (18.52) at an application rate of250 kg NPS ha-1, whereas the lowest number of pods per plant (8.7) came from the unfertilized plot of common bean.

According to Desta Abaychew and Ermias Ejamo (2019), they investigated the effect of different blend NPS fertilizer rates on haricot bean flowering dates, finding that the delay in flowering was recorded at the highest rate of 200 *kg ha-1*, while the earliest flowering occurred in the control group with no fertilizer application. This suggests that increasing rates of NPSB fertilizerledtodelayedflowering,indicatingapreferenceforeachnutrientsourceforvegetative growth.Optimalcommonbeanproductionrelies onvariousagronomicpractices,includingseed rate,spacing,and fertilizerapplication,asrecommended(DeresaShumi *etal*.,2018). Lowplant density can result in reduced yield, increased weed infestation, and poor radiation-useefficiency, while high plant density may lead to lodging, reduced light penetration, decreased photosynthetic efficiency, and lower yield (Yucel Derya, 2013). Achieving high and stable yields in haricot beans requires proper plant arrangement at suitable densities (Kolarić *et al*., 2014).

AgronomicPracticesSuitableforHaricotBeanCultivation

Ethiopian economy is characterized by low levels of productivity and subsistence farming system that has resulted hand to mouth production. The only way to increase the agricultural production from small scale to large scale and export level is to increase the productivity per unit area and time (Mitiku Woldesenbet, 2014). Maximum yield of a particular crop in a given environment can be obtained at row spacing where competition among the plants is minimum. This can be achieved with optimum spacing which not only utilize soil moisture and nutrients more effectively but also avoids excessive competition among the plants (prof.Peter Kumua, 2017). There are many factors that affect productivity in agriculture. These factors are plant species and cultivars, agronomical techniques, soil and climate factors. Seeding rates is important agronomical technique affecting the yield of any crops. Earlier studies have also shown that seeding rate or planting density is an important factor affecting yield of grain legumes(BirhanuTassew *etal*.,2020).InEthiopiamostlyharicotbeancropcanbegrowthwith intercroppingofmaizeand solecrop. Its abilityto fix nitrogen also means that it can encourage much-needed, even longer term improvements in soil fertility, and it provides an economic advantage to small farm holdings as an alternative source of protein, cash income, and food security (Mageje Masa, 2014).

Low yield of common bean in Ethiopia is attributed to several production constraints which include lack poor Agronomics practices such as untimely and inappropriate field operations, inappropriate plant density, weed infestation, low soil fertility, water stress, diseases and insect pests. Increase in yield can be ensured, by maintaining appropriate plant population through different planting patterns (Maguje Masa 2014; Tamado Tana and Abdulatif Ahmed 2017).

EconomicEvaluation ofHaricot BeanProduction

In Ethiopia, common bean is one of the most important cash crops and source of protein for farmers in manylowlands and mid-altitude zones. The country’s export earnings is estimated to be over 85 % of export earnings from pulses, exceeding that of other pulses such as lentils, faba bean and chickpea (Negash Hailu, 2007).Common bean ranks third as an export commodity in Ethiopia, contributing about 9.5 % of total export value from agriculture (FAOSTAT, 2010).

To support both the growth in domestic and export bean markets, the Ethiopian Institute of Agricultural Research (EIAR) has developed a range of high yielding, multi-disease resistant beanvarieties(Alietal.,2003).Thefocusofthisgeneticimprovementprogramhasbeenonthe pure red and white beans to support the commercial sector (Ali et al., 2003). Within the red bean types, the most favored and most commercially accepted varieties include Red Melka, a mottled medium sized red; Red Wolaita, a medium sized pure light red; and Nasser, a small pure dark red variety (Ferris, 2008).

Haricot bean is also one of the most important cash crops and source of protein for farmers in many lowlands and mid-altitude zones. The country's export earnings is estimated to be over 85% of export earnings from pulses, exceeding that of other pulses such as lentils, faba beanand chickpea (Fissha and Yayis, 2015).

Haricot beans are mostly consumed in countries where they are produced. Countries with the highest rates of consumption per capital (in Central America, Caribbean, East Africa and some Asian economies) produce beans and also import them at varying levels, depending on the harvest, for meeting the internal demand. Considering the global imports and exports of dry beans between 2008 and 2012, it seems that 15 to 20% of theworld annual production (around 4MTonaverage)istradedinternationally.Myanmar,ChinaandtheUnitedStatesarethemain exporters, with India and the European Union being the largest importers (FAOSTAT, 2015). Globally, the annual production of green and drybeans is 17 Million tons (FAO, 2010), which makes the crop the most widely utilized of legumes. It is produced for its green pod and dry seed which are both edible.

It is also the major staple food supplementing the protein source for the poor farmers who cannot afford to buy expensive meat. Common bean is high in starch 49%, protein 21.4% and dietary fiber 22.9% and is also a good source of minerals and vitamins including iron,potassium selenium, molybdenum, thiamine, vitamin B6, and folic acid (ferrs, 2008).

The crop ranks second next to faba bean in the country in area of production (CSA, 2018). The major haricot bean producing regions are Oromia, Southern Nations Nationalities and Peoples Region (SNNPR) and Amhara. Their share to the national common bean production is 44.45% for Oromia, 31.01% for SNNPR and 21.67% for Amhara (CSA, 2018).in Ethiopia product and productivityofharicotbeanislowduetodifferentconstraintslikeinappropriateinterrow spacing and blend NPS fertilizer rate.

Importanceof EconomicAnalysisforTechnologyRecommendation

Haricotbean(Phaseolus Vulgaris L.)iscultivated andgrowinginovercontinentsofthe world exceptAntarctica(PeptsP.,1998).Haricotbeanisgrownascashcropbylarge-andsmall-scale farmers in East Africa The immature pods and seeds areproduced and marketed fresh, canned or frozen produce (FOASTAT, 2018). Ethiopia is relatively new source of supply and recent investments by a number of international companies from Italy, UK and Turkey indicate that market prospects are good (CIAT, 2008).

Its Production and productivitydetermined by it genetic potential and environment to which the crop is exposed (CIAT, 2006). Improving one or combination of potentially yield limiting factors may lead to an increase in its productivity In Africa, specifically in Ethiopia Haricotbean has low yield and qualitydueto both biotic and abioticfactors. Factorsassociatedto biotic factors includes disease and pests, varieties with low yield potential and susceptibilityto disease and pests whereas abiotic factors are associated with soil related problems and N and P deficiency from the soil are the most common problems. (Dessalegn Lamesgn, 2003).due to continuous application of inorganic fertilizer soil fertilityleads to decreased ,beside this the cost of inorganic fertilizer is increased so growing haricot bean is economical important to replaced urea fertilizer by nitrogen fixation. Soil fertility may amended apply straw of legumes crops.

The main causes of low productivity at farmer fields are a poor technology level utilization of low agricultural input and cropping in low fertility soils, especially with low N content (Beebe*etal.*,2013).Soilfactorssuchasnutrientdeficiencylikelowsoilnitrogenandphosphorus,and acidic soil conditions are important limitations for common bean production in most of the common bean growing areas (Graham *et al*., 2003). In common bean, symbiotic N fixationrates, seed protein level and tolerance to phosphorus deficiency are low in comparison to other legumes (Broughton et al., 2003).

In Ethiopia, inoculation is new technology. However it is not widely used by the farmers but Rhizobium strains were selected and distributed to the farmer. Inoculation significantly improved nodule number per plant as compared with inoculated treatment; this is because of inoculated bacteria strain had good nodulation inducingcapacityover the native soil Rhizobium population (Habtamu *et al.*, 2017). Poor crop stands and low yields in dry bean have been reported to be associated with lack of inoculationof seeds prior to plantingwhich also results in little nitrogen contributed to the crop

CHAPTER3.MATERIALSAND METHODS

Descriptionsofthestudy Area

The field experiment was carried out during 2022-2023 cropping season of 2022-2023 in Hulet Eju Enesie District in northwestern Ethiopia, Figure 1. The experimental site is located at latitudes 10° 40′ 00″ to 11°10′ 00″ N latitude and 37°40′ 0″ to 38°10′ 0″ E longitude (Figure 1). It is located about 120km east of the capital city of the Amhara National Regional State, Bahir Dar, and 202km north of the administrative zone, Debre Markos. It is 363kilometers to the north of Addis Ababa. The district is located between 1290 and 4036 meters above sea level. Here, the Abay is crossed by the Sabero Dildey, commonly referred to as the "Second Portuguese Bridge" or the "Broken Bridge," which links Hulet Eju Enese with Este Woreda in South Gondar (Abebe Chane, 2021).

Agriculture provides a livelihood for more than 98% of the population. They are involved in livestock and crop cultivation (Assefa *et al.*, 2016). Haricot bean is most legume crop which dominantlygrowthinthestudyarea.Accordingto huletejuenesieagriculturalextensionofficer one quarter of production area cover by haricot bean but, there are many natural and agronomic factors hindering exploitation of the yield potential of this crop. Most farmer growth haricot bean by in poor agronomic practice such as, appropriate fertilizer application and inappropriate spacing.

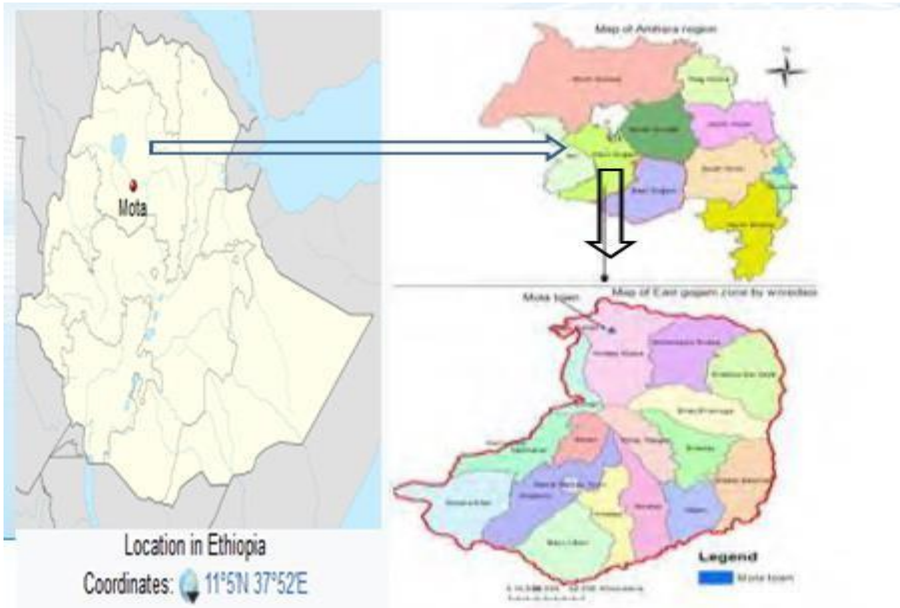
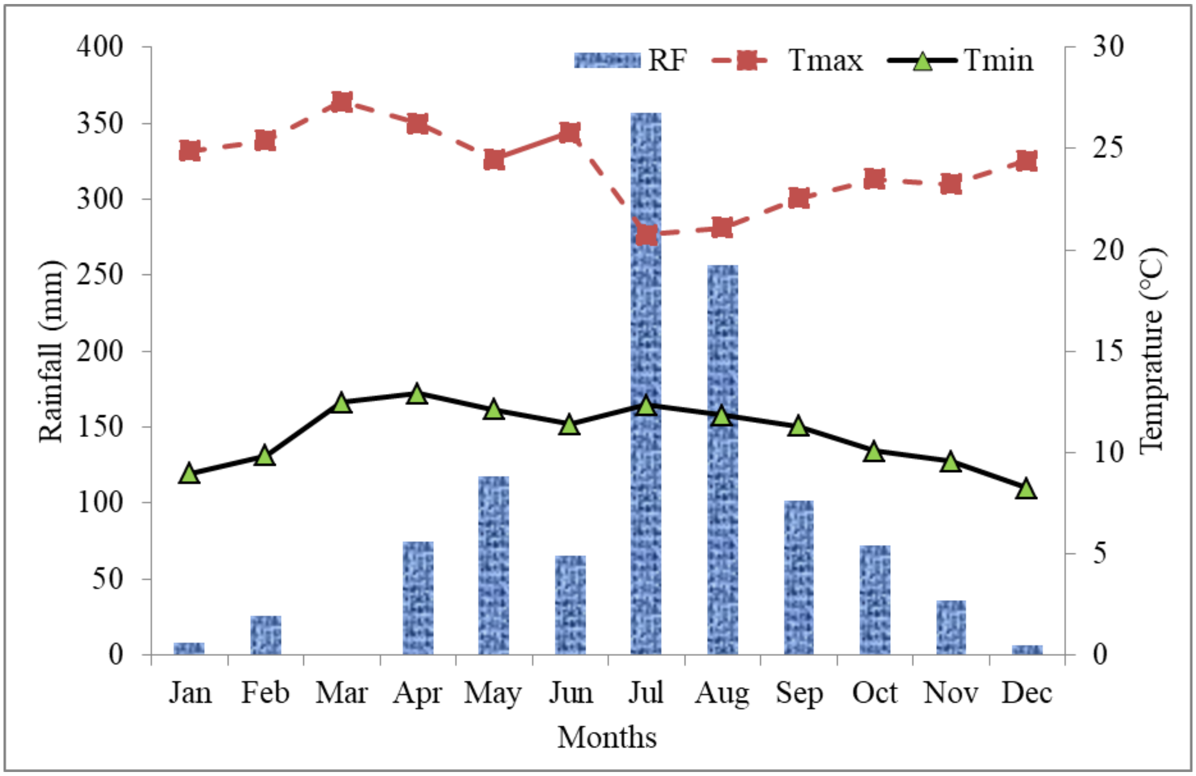


Figure31.Map ofthestudy area

The agro-ecology of the area is predominantly classified as Weina-Dega (2,387–2,555 meters above sea level) with temperatures ranging between 18°C and 24°C and an average annual rainfall of 1,190 mm (WAO, 2011).. However, the peak rainfall season occurs from July to September.Duringtheexperimentalyear,thetotalannualrainfallcollectedwas1,123mm, with mean annual maximum and minimum temperatures of 24.26°Cand 10.87°C, respectively.



Sources Amharametrologystation from 2022-2023

Figure 3. 2.Monthly mean rainfall, maximum and minimum temperatures of the experimental site during 2022/2023 main growing season

Soilsamplingandanalysis(SoilPhysicalandChemicalPropertiesofthe Experimental Site)

Soil samples were taken randomly in zig-zag pattern before planting from the experimental site at adepth of0-30 cm across theexperimental field from 10 spots usingan augerbeforeplanting and the soil were composited to one sample based on procedures described by Munson and Nelson (1993). The collected soil samples were composited and analyzed in Amhara DesignandSupervisionWorksEnterpriseLaboratorycenter,soilchemistryand waterqualitysectionto determine some of the important physio chemical properties of a soil including soil texture, soil pH, organic carbon, available phosphorus, total nitrogen, Cation exchange capacity (CEC), and electrical conductivity. Another composite sample for testing available sulfur was also submitted.Thesoilwasbrokenintosmallcrumbs andthoroughlymixed.Thesoiltobeairdried and sieved through a 2 mm sieve. Soil texture was determined by the Bouyoucos hydrometer method(Bouyoucos,1962),organiccarbon(OC)usingtheWalkleyandBlackmethod

(Walkley and Black, 1934), total nitrogen (TN) by the Kjeldahl method (Bremner and Mulvaney, 1982), available phosphorus (Av.P) by the Bray-II method (Bray and Kurz, 1945), Available sulfur (S) was measured using turbidimetric method (ATA) and soil reaction (pH)was measured using a pH meter (Chopra and Kanqwar, 1976). Electrical conductivity (EC) and Cation exchange capacity (CEC) were determined bythe Rhoades method (Rhoades, 1996) and Hesse method (Hesse, 1972), respectively.

Based on initial soil analysis, the experimental site was found to be characterized by sandy clay loam soil texture, with aparticle size distributionof 49% sand, 23% silt, and 28% clay. The soil pH value of the experimental site was 5.62. This indicates that the soil reaction was found to be moderatelyacidic as determined byMurphy(2007). Theorganic carbon (OC) and total nitrogen (TN)percentagesofthesoil attheexperimentalsitewerecategorizedas medium,withvaluesof 2.02%and 0.15%, respectivelyas noted byTekalign Tadesse(1991). While, according to Olsen *et al*. (1954), the availability of phosphorus at the experimental site was observed to be low,with a concentration of 9.85 ppm. Remarkably, the soil at the experimental site exhibited a notably high Cation Exchange Capacity (CEC) of 57 c/mol/kg, as evaluated by Hazelton and Murphy (2007). In contrast, the electrical conductivitymeasured a very low value of 0.05 ds/m, as reported by Landon (1991).

Table 3. 1.Major soil physical and chemical characteristics of the experimental field before planting in 2022 cropping season in Hulet Eju Ensie District, North Western Ethiopia

Soil property	Units	Values	Rating	Reference
Particlesizedistribution				
Sandy	%	49		
Silt	%	23		
Clay	%	28		
Textural class		Sandy clay loam		USDA(1987)
Soilchemical properties				
PH	-	5.51	Slightlyacidic	Murphy (2007)
OrganicCarbon	%	2.02	Medium	Tekalign Tadesse (1991)
TotalNitrogen	%	0.15	Medium	TekalignTadesse(1991)
AvailableS(mgkg-1)	%	14.5	low	EthioSIS(2014)
AvailablePhosphorus	Ppm	11.56	High	Olsen*et al*. (1954),
Cationexchangecapacity	C/mole	45.2	High	HazeltonandMurphy (2007)
ElectricalConductivity	ds/m	0.075	Low	Landon (1991)

ExperimentalMaterials

Haricot bean Variety “Ser 119” varietywas used in the experiment as the test crop. This variety was released from Melkasa in 2004 E.C. this variety was selected due to wide adapted in the study area (Table 3.2). This variety was collected from the Ethiopian Institute of Agricultural Research together with its full production package. The fertilizer sources were blended NPS fertilizer (19-38-7).

Table 3.2. Agronomic and morphological Characteristics of planting materials (Haricot bean variety) Registered/Released by EIAR, 2011

Description	HaricotbeanvarietyreleasedEIAR
Adaptationsarea	Lowland-Midaltitude
Altitude (m.a.s.l.)	1450-2000
RainFall(mm)	1500-1800
Seedrate(Kgha^{-1})	100
Seed color	Red
ResearchField	33
FarmerField	25
YearofRelease	2004 E.C
Breeder/Maintainer	Melkssa/EIAR

Source:MoA,2011.PlantVarietyrelease,ProtectionandseedqualityControlDirectorate. Crop Variety Register Issue number 14.

ExperimentalDesignsandTreatment

Thefield experiment consistedof12 treatments with fourlevels ofNPS fertilizerrates(61,121, 182, and 243 kg ha-^{1}) and three inter-row spacing (30 cm, 40 cm and 50 cm). The experiment was laid out in a randomized complete block design (RCBD) with three replications. A field layout was prepared, and each treatment was randomly assigned to experimental plots within a block using a lottery system (Figure 3.2) with three replications. The gross plot size was 6m x 2m (12m^2), and the net plot size was 5.8m x 1.2m (6.96 m. There were 20, 15, and 12 rows under 30, 40, and 50 row spacing, respectively. The spacing between plants, adjacent plots and blocks were 10 cm, 0.5 m and 1 m, respectively.The one outer most row from each side andone plant from both end of each row were considered as a border and one row was used from destructive sampling.Thus, the net plot sizes was: three rows of 5.8 m length (3 rows×0.5 m× 5.8m=8.7m2)for50 cm,fourrowsof5.8mlength(4rows×0.4m×5.8m=9.28m2)for40 cm, and five rows of 5.8 m length (5 rows×0.3 m × 5.8 m = 8.7 m2) for 30 cm.

ExperimentalProcedure

The experimental land was initially properly plowed using oxen, a disk, and a harrow with human labor assistance. The field was plowed three times, with the final plowing used for seed covering as per the design specifications.A field layout was prepared, and each treatment was randomlyassigned to experimental plots. The plots wereprepared accordingto the layout of the design and manually leveled. The seeds were directly placed at a depth of 10cm with inter-row spacingof30cm,40cm, and50cm intherespectiveplotswiththeintra-rowspaceof10cm.The NPS fertilizer rates (61, 121, 182, and 243 *kg ha-1*) were applied at sowing in their respective plots. A haricot bean seed rate of 100kg ha^{-1} was used for this study. Each plot received thesame agronomic practices, such as weeding, pest and disease protection at all stages of crop growth and development. The crop was harvested when they reached maturity.

DataCollectionandMeasurements

Phenologicalparameters

Days to 50% emergence: The number of days to 50% emergency was determined by counting the number of days from the date of sowing to the date when 50% of the plants had emerged in each plot through visual observation.

Daysto50% flowering:Thenumberofdaysto50%floweringwas determinedbycountingthe number of days from the date of sowing to the date when 50% of the plants had flowered ineach plot through visual observation.

Days to 90% physiological maturity (DPM): Days to physiological maturity was recorded by counting the number of days from date of sowing to the date when 90% of the plants changed green color to yellowish, lost its water content and attained to physiological maturity.

Growth parameter

Plant height (PH): The height of the plant was collected bymeasuringthe length from the base of the main stem at ground level to the tip of the panicle. This was done by randomly selecting ten plants from each net plot area at the physiological maturity of the crop, and their mean height was taken.

Numbers of branches per plant (NBPP): The number of branches per plant (NBPP) was determined by counting the primary branches on the main stem for each plant harvested at maturity. This involved harvesting 10 randomly sampled plants from all harvested rows of the plot and recording the average number of branches per plant.

Leaf area index (LAI): The Leaf Area Index (LAI) for haricot bean plants was determined by capturing field photographs using a digital camera (Coolpix 4500, Nikon, Tokyo, Japan) within 1m^2 quadrats. Photographs were taken from a height of 1 meter above the ground. Measurements were conducted shortly before sunset during the full vegetative stage of haricot bean growth. All photographs were transferred to a computer and saved as uncompressed, high-resolution files. Subsequently, these files were directly imported into the LAI calculator for analysis, following the methodology outlined by Yayeh Bitew *et al*. (2020).

Number of total nodules (ND): The number of nodules was determined by counting the number of nodules per plant at flowering stage from ten randomlyselected plants from each net plot area and their average value was recorded. The number of effective nodule also accounted and identified

Yield parameter

Number of pod per plant: The number of pod per plant (NPPP) was determined by counting the number of pod per plant at maturity from ten randomly selected plants from each net plot area after physiological maturity and their average value was recorded

Numbers of seeds per pod (NSPP): Number of seeds per pod was determined by counting the number of seed per pod from ten randomly taken pods from each net plot area was taken after physiological maturity and their average value was recorded

Hundred seed weight (HSW): It was determined by counting 100 seeds by using an electronic automatic seed counter and weighing those counted grains sampled from the net plot using a sensitivebalanceofprecision+0.001g.Thethousandgrainsweightwasrecordedafterthegrain was adjusted to 10% moisture content.

Above-ground dry biomass (AGDM): The plants in the net plot area (that was harvested for yield estimate) harvested at the point where they are attached to the ground, collect and sun dried until the constant weight attained. Dried plants were weighed to determine the biomass yield on plot basis and converted into hectarebasis to determine total biomass yield per hectare.

Grain Yield (GY t ha-^{1}): Grain yield was measured bytakingthe weight of the grains threshed (after sun dried) from the net plot and converted to kilograms per hectare after adjusting the grain moisture content to 10%. The moisture correction factor was done by using the following formula.

$$Adjusted\ Yield = \frac{100 - measured\ moisture\ content\ \%}{100 - 10} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Harvest index (HI %): Harvest index values of each treatment were computed as the percent ratio of grain (economic) yield to the total biomass (straw +grain) yield per plant from the respective treatments and expressed in percentile terms by using the formula of Donald as,

$$\text{Harvest Index} = \frac{Economic\ yield\ (kg\ per\ ha)}{Total\ biological\ yield\ (kg\ per\ ha)} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Data Analysis

Data were subjected analysis of variance (ANOVA) using the statistical procedures outlined by Gomez and Gomez (1984) with *using SAS-JMP-16 software*. Normality was checked using the scatter plot method. Mean comparison was performed using LSD when the ANOVA of the agronomicattributes yieldedsignificantatanyprobabilitylevel.Withthesamesoftware,simple correlation analysis was carried out to investigate the strength of the associations among phonological parameters, yield traits, and grain yield of the haricot bean. The value of r (correlation coefficient) lies within the range of -1 and +1, with a value close to +1 or -1 represents a strong linear relationship, a value of r close to zero means the linear relationship is very weak and an intermediate value of r indicates the portion of variation in one variable that accounted for by the linear function of the other variable.

PartialBudgetAnalysis

An economic analysis was done using partial budget procedure described by CIMMYT (1988). CostsofSeed,NPSfertilizer andlaborfor plantingandfertilizationwere regardedasinputcost, while revenue from both grain and straw of the tested crop served as output factors. Additional production expenses, including labor for land preparation, harvesting, and threshing, were assumed to be consistent across all treatments. The partial budget analysis was performed using the prevailing costs of inputs during sowing and farm-gate prices for outputs during the harvest period (June to September). All expenses were computed as the average value between 2022and 2023, on a per-hectare basis. The price of NPS fertilizer, the seed cost of haricot beans, and labor costs for fertilizer application were considered as variable expenses. Costs that remained constant across all treatments were categorized as fixed costs and were excluded from the analysis of marginal rate of return. Consequently, the price of NPS fertilizer stood at 15 Ethiopian Birr per kilogram, while the mean labor cost for NPS fertilizer application was estimated at 200 Ethiopian Birr per day. Additionally, the costs per kilogram of grain and straw yield were computed at ETB 19 and ETB 2, respectively, based on the average local market prices between Junes to September. To reduce the gap between experimental plot yields and yield typically achieved by farmers, the yields of the treatments were adjusted downward to 90%. Total variable cost (TVC) was computed by summing the costs of inputs during sowing, denominated in Ethiopian Birr. Gross benefit (GB) was determined as the total income from selling grain and straw. Net benefit (NB) was derivedbysubtracting GBfromTVC. Treatments were then arranged in ascending order based on TVC value. Treatments with higher NB and lower TVC than the preceding treatment were retained for further analysis, while those with lower NB and higher TVC were excluded. The selected treatments were subjected to marginal rate of return (MRR) analysis, calculated as the ratio of change in NB to change in TVC between two consecutive treatments. Subsequently, the selected treatments were ranked based on NB value. The first-, second-, and third-ranked treatments were identified as the most economically viable agronomic practices. Before calculating Marginal Rates of Return, a preliminaryDominance Analysis was conducted. Treatments were sorted byincreasingvariable costs (TVC), and net benefits (NB) were noted. Any treatment with higher TVC but lower or equal NB compared to the preceding treatment was labeled as "D" for dominated. This analysis highlights the importance of prioritizing net benefits over yields for enhancing farmers' income. Marginal Rate of Return (MRR) was then calculated by dividing the change in net benefit (ΔNB)bythechangeintotalvariablecost(ΔTVC),expressedasapercentage.Amongthenondominatedtreatments,theoneyieldingthehighestnetreturnandaMRRexceedingthe minimum acceptable to farmers (100%) was recommended.

Chapter4.RESULTSAND DISCUSSION

EffectsofInterRowSpacingandBlendedNPSFertilizerRateonPhenological Parameters of Haricot Bean

Daysto50%flowering

Analysis of variance (ANOVA) revealed that days to 50% flowering was highly significantly ($p<0.01$) influenced by both the main effect of inter row spacing and NPS fertilizer rate. However, the interaction effect of inter row spacing and NPS fertilizer had no a significanteffect on days to 50% flowering (Appendix Table 2).The longest days (49.46) to reach 50% flowering was recordedat 30cm row spacing while the shortest days (48.14) to reach 50% flowering was recorded from at 50cm row spacing (Table 4.1). The results obtained from this study clearly exhibited that the increasing row spacing shorted the time required to attain day's to50% of flowering. The reason for recording longest days to reach 50% of flowering at narrow plant spacing might be due to competition for resources, limited light penetration and reduced air circulation leading slower growth and development. As a result, the plants may take longerto reach the flowering stage. The result of the present finding was inconsistent with Mulatu *etal.* (2017) on haricot bean who reported that highest plant population density plants flowered earlier and the lowest plant population density flowered late.

With respect to NPS fertilizer rate, the longest days (50.04) to reach 50% flowering was recorded from treatment which received 182 kg NPS rate $ha^{-1,}$ while the shortest days (48.07) was recorded from 61 kg NPS rate ha^{-1} (Table 4.1). The results showed that the increasing of application of blended NPS fertilizer rate prolonged days to attain 50% flowering of haricot bean. This might be due to excessive application of Nitrogen in the soil can promote vegetative growth at the expense of reproductive growth which leads to plants may focus more on producing leaves and stems rather than flowers and pods. However, this result also showed that increasing the rate of Blended NPS fertilizer rate more than optimum level shortens the time to reach 50% of flowering. Delayed flowering and pod formation can result in a longer time to reach physiological maturity. This finding was agreed with Shumi (2018) who reported that increasing NPS rate from 50 to 200 kg ha^{-1} significantly prolonged the period to 50% flowering ofcommonbean(*PhaseolusVulgaris*L.)EndriasChinasho(2017)alsostatedthatincreasing

NPSratefrom0 kgNPS $ha^{-1}$to 100 kg NPS ha^{-1} increased the numberofdays required to reach 50% flowering from 39.61 days to 44.11 days.

Daysto90%physiological maturity

Analysis of variance (ANOVA) showed that days to 90% of physiological maturity of haricot bean was significantly influenced by both the main effects of inter row spacing *($p<0.05$)* and blended NPS fertilizer rate *($p<0.01$)*. However, the interaction effects of inter row spacing and blended NPS fertilizer did not show a significant effect *($p>0.05$)* on days to 90% physiological maturity (Appendix Table 3). The highest number of days required to attain 90% physiological maturity (80.31 days) was record from at 30 cm row spacing while the shortest days to reach 90%physiological maturity(79.06 days) was recorded from50cm row spacing (Table4.1). The result indicates that increasing inter row spacing shortened days to attain 90% physiological maturity. This might be due to planting crops with narrow spacing can create a dense canopy, limiting sunlight penetration and air flow. This can lead to slower and delayed physiological maturity as the plants may struggle to receive adequate resources for optimal development. Additionally, the increased competition for nutrients and water in a narrow spacing can also contribute to delayed maturity.The result of the present finding is in contradictswith this result of Schatz *et al*. (2000) who reported that dry bean plants matured earlier at highest plant population density and matured late at lowest population density.

Regarding to the main effect of blended NPS fertilizer, the maximum number of days was recorded from treatment which received 182 kg^{-1} of blended NPS fertilizer (80.67days) while, the minimum number of days was recorded from treatment which received 61kg-1of blended NPS fertilizer (78.72 days) (Table 4.1.). The result of the present finding regarding to blended NPS fertilizer on days to 90% physiological maturity indicates that the number of days to reach 90% physiological maturity increased with increasing the rate of blended NPS fertilizer rate. This might be due to the application of high level of NPS fertilizer can promote excessive vegetative growthincrops,suchasincreasedleaf andstemdevelopment.Thiscandivertenergy awayfrom reproductive processes (floweringand fruiting)leads to delayonset offloweringand fruitingstages.Thisresultinlinewiththefindingof Endrias(2017)whoreportedincreasing

NPSratefrom0kgNPSha-1to100kgNPSha-1increasedthenumberofdaysrequiredto reach physiological maturity.

Table 4.1. Phenological responses of haricot bean for inter-row spacing and blended NPS fertilizer rate during 2022/2023 main growing season in Hulet Eju Ensie District, North Western Ethiopia

Treatmentsand Statistics	Mean	
Inter-rowspacing(cm)	DF	DPM
30	49.46^{a}	80.31^{a}
40	48.56^{b}	79.46^{ab}
50	48.14^{b}	79.06^{b}
LSD (5%)	**	*
±SE	**0.22**	**0.32**
FertilizerRateKg^{-1}(NPS)		
61	48.07^{b}	78.72^{b}
121	48.60^{b}	79.85^{ab}
182	50.04^{a}	80.67^{a}
243	48.17^{b}	79.21^{ab}
LSD (5%)	**	**
±SE	**0.26**	**0.37**
CV(%)	**1.61**	**1.42**

Where, DE=days to 50% emergency; DF=days to 50% flowering, DPM=days to physiological maturity, ***=very highly significant (p<0.001);**=highly significant (P<0.01); CV= Coefficient of variance; SE =Standard Error; LSD = least significant difference; means with in the same columns followed by the same letter (s) are not significantly different.

EffectsofInterRowSpacingandBlendedNPSFertilizerRateongrowthparameters of haricot bean

Plant height

Analysis of variance (ANOVA) showed that plant height was significantly *(p<0.001)*influenced by the main and interaction effects of inter row spacing and blended NPS fertilizer, and their (Appendix Table 6).The tallest plant height (61.66cm) was obtained from inter row spacing of 40 cm with the application of 182kg ha^{-1} of blended NPS fertilizer. However, statisticallyatparwiththecombineduseof50cminterrowspacingand61kgha^{-1}ofblended

NPS fertilizer while, the shortest plant height (45.20cm) was obtained from30cminter row spacing with the application of61kgha^{-1} ofblended NPS fertilizer.However,it was statistically on par with the combined use of 30cm inter- row spacing and the application of 121 kg ha^{-1} of blended fertilizer (Table 4.2). The longest plant height recorded from optimum plant spacing is likely due to reduced competition among plants, allowing them to allocate more resources towards vertical growth, resulting in taller plants and optimal development. This can be attributed to increased access to sunlight, water, and nutrients without competing with neighboring plants. The increase in plant height in response to the optimum NPS applicationrate might be due to the maximum vegetative growth of the plants under higher N, P and S availability as nitrogen helps in chlorophyll formation, phosphorus establishes strong root system and sulphur enhanced the formation of chlorophyll and encouraged vegetative. Theresult of the present finding agreed with the works of Moniruzzaman *et al*. (2008) who found that plant height was significantly increased up to 160 kg N ha^{-1} and phosphorus at the highest level (120kgP2O5ha^{-1}). Likewise, Nebret and Nigussie(2017)reported that increasingNlevel from0kgha^{-1}to23kgha^{-1}increasedplantheight ofcommonbeanbut,excessiveapplicationof nitrogen containing fertilizers, such as NPS can leads to a decrease in plant height due to nutrient imbalance, vegetative growth promotion and weak stems.

Numberofbranchper plant

Analysis of variance (ANOVA) showed that the number of branches per plant was highly significantly ($p < 0.01$) influenced by both the main effects of inter-row spacing, NPS fertilizer, and their interaction effect (Appendix Table 7). The maximum number of branches per plant was obtained from 40cm inter-row spacing with the application of 182 kg ha-^{1}of blended NPS fertilizer, while the minimum number of branches was recorded from 30cm inter-row spacing with the application of 61kg ha-^{1} of blended NPS fertilizer, but statistically on par with haricot bean seed planted at a row distance of 30cm with the application of 61 kg ha-^{1} and 121 kg ha-^{1} of blended NPS fertilizer, respectively (Table 4.2.) Treatments were received at a row distance of 30cm, 30cm, 40cm, 50 cm, and 50cm with the application of 182 kg ha-^{1}, 243 kg ha-^{1}, 61 kg ha-^{1}, 61 kg ha-^{1}, and 121 kg ha-^{1} of blended NPS fertilizer, respectively. And also, the numberof branches per plant had a similar response to treatments received at 40cm and 50cm inter-row spacingwiththeapplicationof121kgha-^{1},243kgha-^{1},182kgha-^{1},and243kgha-^{1}of blended NPS fertilizer, respectively. The number of branches per plant obtained from optimum row spacing might be due to the fact that optimum plant spacing leads to plants having more space and access to more light and resources, which promotes lateral bud development and branching. This can lead to a bushier plant with multiple branches and a fuller appearance, whereas narrow plant spacing can limit branching as plants compete for resources and grow more vertically to access light, resulting in fewer branches and a more elongated growth habit. Theresultofthepresentfindingwasincontraventionof Biru Adugnaand Tamado Tana(2019), who noted that the interaction effects of NPS rate and row spacing were not significant.

Numberofpod perplant

Analysis of variance (ANOVA) showed that number of pod per plant was very *(P<0.001)*significantly influenced by the main effects of inter-row spacing, blended NPS fertilizer and their interaction effects (Appendix Table 8). The highest number of pod per plant (18.4) was recorded from inter-row spacing of 40cm with the application of 182kg^{-1} of blended NPS fertilizer but, statistically on par with the combined application of 40 cm inter-row spacing of and 50cm with blended NPS fertilizer of 121kg^{-1}, 243kg^{-1}, 121kg^{-1}, 182kg^{-1} and 243kg$^{-1,}$ respectively while, the lowest number of pod per plant (12.3) was recorded from inter-row spacingof30cmwiththeapplicationof61kg^{-1}ofblendedNPSfertilizer(Table4.2).Thereason for recording highest number of pod per plant from treatment which received inter-row spacing of 40cm might be due to when plants have more space; they have access to more light and resourceswhich canpromoteoverallplant growthanddevelopmentincludingpod formation. In agreementwiththeresultofthisstudy,Mulatu *etal*.(2017)reportedthehighestnumberofpods per plant was recorded from lowest plant population density with low rate of blended NPS fertilizer and the lowest number of pods per plant was recorded from the highest plant population density of haricot bean with high rate of blended NPS fertilizer with more resources available, plants can allocate more energy towards pod production resulting in a higher number of pods per plant with the increased NPS rates might be due to adequate availabilityof N, P and Swhichmighthavefacilitatedtheproductionofprimarybranchesandplantheightwhichmight inturnhavecontributed fortheproductionofhighernumberoftotalpods(Shumideresa, 2018).

Number ofseed per pod

Analysis of variance (ANOVA) showed that the number of seeds per pod was very highly significantly ($p<0.01$) influenced byboth the main effect of inter-row spacing and blended NPS fertilizer and significantly ($p<0.05$) influenced by the interaction effects (Appendix Table 9). The highest number of seeds (8.23) was recorded at an inter-row spacing of 40cm with the application of 182 kg of NPS fertilizer, while the lowest number of pods (5.46) was recorded at an inter-rowspacingof30cm with theapplicationof61kgofblended NPS fertilizer(Table4.2). This might be due to a wider inter-row spacing of 40cm; there is more space for the plants to spread out their roots and access nutrients from the soil. Additionally, the higher application of 182 kg of NPS fertilizer would have provided ample nutrients for the plants to thrive, resulting in a higher number of pods. The results of the study clearly demonstrate the significant impactof both inter-row spacing and fertilizer application on pod production. Haricot bean seeds planted with 40cm inter-row spacing and treated with 121 kg and 181kg of NPS fertilizer, as well as those planted with 50cm inter-row spacing and treated with 182kg of NPS fertilizer, exhibit similar responses. The current findings contradict those of Golroudbari and Naghi (2014), who also reported that plant densities did not show a significant effect.

Table 4.2. The interaction effect of inter-row spacing and blended NPS fertilizer rate on plant height, number of branch per plant, number of pod per plant and number of seed per pod in Hulet Eju Ensie District, North Western Ethiopia during the 2022/2023 main growing season.

Treatmentsand statistics		Mean			
Interrow spacing	FertilizerRateKg^{-1}(NPS)	PH	NBPP	NPPP	NSPP
30cm	61	45.20^{d}	3.50^{c}	12.03^{c}	5.46^{d}
	121	45.80^{d}	3.60^{c}	16.56^{ab}	6.33^{bcd}
	182	48.03^{cd}	5.06^{b}	15.76^{b}	6.56^{bc}
	243	48.43^{bcd}	4.83^{b}	15.96^{b}	5.83^{cd}
40cm	61	52.66^{b}	5.16^{b}	15.36^{b}	6.93^{b}
	121	51.23^{bc}	5.43^{ab}	18.33^{a}	7.20^{b}
	182	61.66^{a}	5.99^{a}	18.40^{a}	8.23^{a}
	243	52.80^{b}	5.56^{ab}	18.00^{a}	6.96^{b}
50cm	61	60.43^{a}	4.96^{b}	16.86^{ab}	6.66^{bc}
	121	48.46^{bcd}	5.13^{b}	18.16^{a}	6.70^{bc}
	182	60.86^{a}	5.36^{ab}	17.96^{a}	6.93^{b}
	243	52.06^{bc}	5.43^{ab}	17.93^{a}	6.70^{bc}
LSD (5%)		***	**	**	*
±SE		**0.89**	**0.14**	**0.37**	**0.17**
CV(%)		**2.94**	**4.9**	**3.8**	**4.4**

Where, PH=plant height; NBPP=number of branch per plant, NPPP=number of pod per plant, NSPP=number of seed per pod, ***=very highly significant (p<0.001);**=highly significant (P<0.01);CV=Coefficientofvariance;SE=StandardError; LSD=leastsignificantdifference; means with in the same columns followed by the same letter (s) are not significantly different.

Numberofnodules per plant

Analysis of variance (ANOVA) showed that total number of nodules were significantly influenced by both the main effect of inter-row spacing *(p<0.05)* and blended NPS fertilizer *(p<0.01)*. However, the interaction of inter-row spacing and blended NPS fertilizer did notshow a significant effect *(p>0.05)* on total number of nodules (Appendix Table 4). The highest total numbers of nodules were recorded from inter-row spacing of 30cm (70.64), while the lowest total number of nodules was recorded from inter-row spacing of 50cm (69.59) (Table 4.3). This suggests that, as inter-row spacing increased from 30 cm to 50 cm, the number of nodulesdecreasedandviceversa.Thehighesttotalnumberofnoduleswasrecordedata narrow inter-row spacing. This phenomenon may be attributed to the closer proximity of rootsto nitrogen-fixing bacteria in the soil, leading to more efficient colonization and nodule formation. Additionally, narrow inter-row spacing may result in greater competition among the roots for nutrients and water. This competition could stimulate the plants to form more nodules in response to increased stress. This result contradicts with the findings of Adugna Bedede and Tana Tamado (2019) who noted that the total number of nodules per plant increased with increasing row spacing. They observed that the highest total number of nodules per plant was obtained from 50 cm row spacing, while the lowest total number of nodules per plant was obtained from 20 cm row spacing.

Regarding to blended NPS fertilizer, the maximum total number of nodules was observed with the application of 121 kg ha-^{1} of NPS (72.75), while the minimum total number of nodules was recorded at 243 kg ha-^{1} of NPS (68.63) (Table 4.3). The findings indicate that increasing levels of blended NPS fertilizer up to 121 kg ha-1 of NPS positively influenced nodulation. However, further increases in fertilizer application beyond this optimal level resulted in a decline innodule formation, emphasizing the importance of balanced nutrient application for optimal haricot bean growth. The reason for the recorded maximum number of nodules from the application of 182 kg ha-^{1} of NPS might be due to the increased availability of essential nutrients for nodule formation, such as nitrogen, phosphorus, and sulfur. However, once the level of blended NPS fertilizer exceeded a certain limit, the number of nodules started decreasing. This suggests that there is an optimal level of blended NPS fertilizer that promotes healthy nodule formation in plants like haricot bean, and exceeding this level can be counterproductive.IncontradictwiththeseresultsShumideresa(2018)reportedthatthehighest number of total nodules per plant was obtained from the application of NPS rate of 200 kg ha-^{1} ofNPS.Conversely,thelowestnumberoftotalnodulesofcommonbeanwasrecordedfromthe absence of NPS fertilizer application.

Leafareaindex

The provided table presents the results of an experiment investigating the response of haricot bean to different inter-row spacings and blended NPS fertilizer rates. The leaf area index (LAI) wassignificantlyhigher(4.22)at40cminter-rowspacingcomparedto30cm(2.92)and50cm

(3.29) spacing. Regarding the fertilizer rates, the leaf area index (LAI) was significantly higher (4.34 and 4.09) with the application of 182 kg ha-1 and 243 kg ha-1 of blended NPS fertilizer, respectively, compared to the lower rates of 61 kg ha-1 (2.55) and 121 kg ha-1 (2.93).The LSD (Least Significant Difference) at the 5% level of significance indicates that the differences in LAIamong the inter-row spacing and fertilizer rate treatments werestatisticallysignificant. The coefficient of variation (CV %) for LAI was 12.95%, suggesting a moderate level of variability in the data.

The highest leaf area index observed at 182 kg ha^{-1} could be due to the fact that the higher amounts of blended NPS fertilizer provided the plants with more nutrients can promote increased leaf growth and expansion leading to better growth and higher leaf area index. On the other hand, the lower amount of blended NPS fertilizer maynot have provided enough nutrients foroptimal plant growth, resulted in lower leaf areaindex. This findingindicatesthat exceeding the optimum level of blended NPS fertilizer application can have several negative effects on plant growth and health such as nutrient imbalances, reduced root growth decreased nutrient uptake and increased susceptibility to pests and diseases resulted to lower leaf area index. This result was in line with Wondwosen (2017) who reported the increase in leaf area and leaf area index with increased rates of NP application from 0 kg N and 0 kg P2O5 to 36 kg N and 92 kg P2O5 ha^{-1}

Table 4.3. Responses of number of nodules and leaf area index of haricot bean to inter-row spacing and blended NPS fertilizer rate in Hulet Eju Ensie District, North Western Ethiopia during the 2022/2023 growing season.

Treatmentsand Statistics	Mean	
Inter-rowspacing(cm)	ND	LAI
30	70.64^{a}	2.92^{b}
40	70.56^{a}	4.22^{a}
50	69.59^{b}	3.29^{b}
LSD (5%)	*	***
±SE	**0.31**	**0.20**
FertilizerRateKg^{-1}(NPS)		
61	69.42^{bc}	2.55^{b}
121	70.25^{b}	2.93^{b}
182	72.75^{a}	4.34^{a}

243	68.63[c]	4.09[a]
LSD (5%)	*******	*******
±SE	**0.36**	**0.23**
CV(%)	**1.55**	**12.95**

Where, ND=number of nodules; LAI=leaf area index; ***=very highly significant (p<0.001);**=highly significant (P<0.01); CV= Coefficient of variance; SE =Standard Error; LSD=leastsignificantdifference;meanswithinthesamecolumnsfollowedbythesameletter (s)arenot significantlydifferent

Abovegrounddrybiomassyield

Analysis of variance (ANOVA) revealed that biomass yield was very highly significantly ($p< 0.001$) influenced by both the main effects of inter-row spacing and blended NPS fertilizer. Additionally, the interaction effect inter-row spacing and blended NPS fertilizer were found to have significant ($p > 0.05$) influence on biomass yield (Appendix Table 10). The highest biomass yield (6.10t ha-^{1}) was observed when utilizing a 40cm inter-row spacing coupled with the application of 182 kg ha-^{1} of blended NPS fertilizer. In contrast, the lowest biomass yield (4.63) observed at a 30cm inter-row spacing with the application of 61 kg ha-^{1} of blended NPS fertilizer (Table 4.4). Interestingly, a similar biomass yield was recorded when applying a combined application of 30cm inter-row spacing with 121 kg ha-^{1} of blended NPS fertilizer. Thisresult showedthat,therewasanoverallincreasingtrendinmeanbiomass yieldwithhigher blended NPS fertilizer rates. The reason for observed highest biomass yield at 40cm inter-row spacing could be efficient plant growth by minimizing competition for resources, while higher fertilizer rates positively influence overall plant productivity by addressing nutrient limitations. Together, these factors contribute to the higher biomass yield observed in haricot beans. Within the 30cm inter-row spacing, there was a parallel response between treatments received 121 kg ha^{-1} (4.80) and 243 kg ha-^{1} (4.76) of blended NPS fertilizer. This implies that, despite the difference in fertilizer rates, these treatments resulted in comparable mean biomass yields.These findings align with those of Adugna Bedede and Tana Tomado (2019), who observed a significant ($p < 0.05$) interaction effect between NPS rates and inter-row spacing on the aboveground dry biomass of common bean. The increase in dry matter yield attributed to the applicationofNPSfertilizercouldstemfromthesufficientprovisionofnitrogen,phosphorus, and sulfur. This enhanced nutrient availability may have led to an increase in the number of branches per plant and leaf area, consequently augmenting the photosynthetic area and the number of pods per plant. Ultimately, this cascade of effects contributes to enhanced drymatter accumulation.

Adjustedgrainyield:

Is the average yield adjusted downward by a 10% to reflect the difference between the experimental yield and yield of farmers.

Analysis of variance (ANOVA) exhibited that grain yield was significantly *($p<0.001$)*influenced byboth the main effects inter-row spacing and blended NPS fertilizer.Additionally, the interaction effects between inter-row spacing and blended NPS fertilizer showed significant *($p<0.001$)* effect on grain yield (Appendix Table 12). The highest grain yield (5.59 t $ha\text{-}^1$) was obtained from a combined application of 40cm inter-row spacing with 182kg ha^{-1} of blended NPS fertilizerratewhich was statisticallyon par with acombined application of40cm inter-row spacing with 121 kg $^{-1}$ of blended NPS fertilizer.Contrastingly, the lowest grainyield (4.31t$ha\text{-}^1$) observed at a 30cm inter-row spacing with the application of 61 kg $ha\text{-}^1$ of blended NPS fertilizer which was statistically in parity with a combined application of 30cm inter-rowspacing with 243 kg -^1 of blended NPS fertilizer (Table 4.4). Maguje *et al.* (2017) similarly found that the highest grain yield of common bean (2125 kg $ha\text{-}^1$) was achieved with a row spacing of 30 cm, while the lowest grain yield (1807 kg $ha\text{-}^1$) was observed with a row spacing of50 cm. Thereason for therecorded maximum grain yield at 40cm inter-rowspacingwith 182 kg of NPS fertilizer application could be an ideal combination that maximizes nutrient availability and minimizes competition among plants, resulting in optimal growth conditionsand higher yields. Conversely, theminimum grain yield at 30cm spacingwith 61kg$ha\text{-}^1$ of NPS fertilizer application could be due to reduced nutrient uptake and increased competition for resources among densely planted beans, leading to poorer growth and lower yields despite fertilizer application. This indicates that, appropriate spacing and fertilizer management are crucial factors influencing grain yield in haricot bean cultivation. The present findings are consistent with those reported by Endrias (2017), who observed the highest grain yield of common bean (2097 kg $ha\text{-}^1$) with the application of 100 kg $ha\text{-}^1$ of NPS fertilizer , while the lowest grain yield (665 kg $ha\text{-}^1$) was recorded in the absence of NPS fertilizer application.

Table 4.4.The interaction effect of inter-row spacing and blended NPS fertilizer rate on above-ground biomass yield and adjusted grain yield in Hulet Eju Ensie District, North Western Ethiopia during the 2022/2023 growing season.

Treatmentsand statistics		Mean	
Inter-rowspacing	FertilizerRateKg-1(NPS)	AGDBY(tha-1)	AGY(tha-1)
30cm	61	4.63[f]	4.31[f]
	121	4.80[f]	4.37[ef]
	182	5.00[ef]	4.52[abc]
	243	4.76[f]	4.32[f]
40cm	61	5.03[ef]	4.55[abc]
	121	5.63[bcd]	4.58[a]
	182	6.10[a]	4.59[a]
	243	5.56[cd]	4.55[ab]
50cm	61	5.23[de]	4.45[cde]
	121	6.00[ab]	4.50[abc]
	182	5.93[abc]	4.39[def]
	243	5.50[d]	4.47[bcd]
LSD (5%)		*	***
±SE		**0.08**	**0.01**
CV(%)		**4.2**	**1.28**

Where, AGDBY=above grounddrybiomass yield; AGY=adjusted grain yield; ***=veryhighly significant(p<0.001);**=highlysignificant(P<0.01);CV=Coefficientofvariance;SE =Standard Error; LSD= least significant difference; means with in the same columns followed by the same letter (s) are not significantly different.

Harvestindex (%)

Analysis of variance showed that harvest index was very highly significantly (p<0.001) influenced by both the main effect of inter-row spacing and Blended NPS fertilizer. However, the interaction effect of inter-row spacing and blended NPS fertilizer did not exhibit a statisticallysignificant effect (p>0.05) on the harvest of haricot beans (Appendix Table 13).The highest harvest index (75.44%) was obtained at 30cm inter-row spacing, whereas the lowest harvest index (57.51%) was obtained at 50cm inter-row spacing(Table 4.5). This trend suggests that as inter-row spacing increases from 30cm to 50cm, the harvest index decreases progressivelyandfurtherwideningthespacingto50cmresultsinafurtherdecreaseinthe harvest index. The reason for recording the highest harvest index at narrower inter-row spacing (30cm) could be the promotion of better resource utilization and allocation towards the harvested portion of the crop, potentially leading to higher crop yields or quality compared to wider spacing conditions (40cm and 50cm). In contradict with this result Mulatu Yihun *et al*. (2017) reported an increased harvest index of haricot bean with decreasing plant density. The highest harvest index of was recorded with thelowest plant population density, whilethelowest harvest index was obtained with the highest plant population density.

WithrespecttoblendedNPS fertilizerrate,thehighestharvestindex (72.73%)wasrecordedfor haricot bean seeds fertilized with 61kg per hectare of blended NPS fertilizer, while the lowest harvest index (59.41%) was recorded for haricot bean seeds fertilized with 182kg ha^{-1} of blended NPS fertilizer (Table 4.5). The high harvest index observed with the low fertilizer rate (61kg ha^{-1}) suggests that this level of fertilizer application provided optimal nutrientavailability, promoting efficient plant growth and reproductive development. Conversely, excessive fertilizer application (182kg ha^{-1}) may have led to nutrient imbalance, hindering plant performance and resulting in a lower harvest index despite the higher input. The presentfindings in contradictwith those of Dhanjal *et al.* (2001), who similarly reportedimprovementsinharvest index valuesof31.60%,31.99%,and33.86%withincreasinglevelsof nitrogen application from zero to 60 and 120 kg ha^{-1} of nitrogen on common bean crops.

Table 4.5. The response of harvest index to inter-row spacing and blended NPS fertilizer rate in Hulet Eju Ensie District, North Western Ethiopia during the 2022/2023 growing season.

Treatmentsand Statistics	Mean
Inter-rowspacing(cm)	HI(%)
30	75.44[a]
40	62.52[b]
50	57.51[c]
LSD(5%)	*****
±SE	**1.08**
FertilizerRateKg^{-1}(NPS)	
61	72.73[a]
121	62.95[b]
182	59.41b[c]
243	75.53[c]
LSD (5%)	*****
±SE	**1.25**
CV(%)	**4.9**

Where, HI=harvest index, LSD=least significant difference, SE=Standard error, CV=coefficient of variation,***=very highly significant difference

PartialBudgetAnalysis

The results of the partial budget analyses revealed that the highest net benefit (119846 ETBha-^{1}) was obtained from a combined application of 40cm inter-row spacing with 182kg ha-^{1} of blended NPS fertilizer rate followed by a combined application of 50cm inter-row spacing with 121kg ha-^{1} of blended NPS fertilizer rate(119148 ETB ha-^{1}). In contrast, the lowest net benefit (76304 ETB ha-^{1}) was obtained from a combined application of 30cm inter-row spacing with 243kg ha-^{1} of blended NPS fertilizer rate. The highest marginal rate of return (MRR) was recorded when haricot been seed planted with 40cm of inter-row spacing with a combined application of 182kg ha-1 of blended NPS fertilizer rate with an acceptable marginal rate of return equals to 5173% followed by a combined application of 50cm inter-row spacing with 121kg ha-^{1} of blended NPS fertilizer rate (MRR =3421%). The highest MRR (5173%) indicates that investingone ETBon the treatment combination of 50cm inter-row spacingwith 121kgha- ^{1} of blended NPS fertilizer rate enables the growers to obtain a return of 51.73 ETB ha-^{1}.

Table 4.6.Results of the partial budget analysis for the combined use of blended NPS fertilizer and inter-row spacing

Treatments	TVC(ETB)	Gross Benefit(ETB)	Net benefit (ETB)	MRR (%)
50cm+61kg-1	6852.000	104350	97498	
40cm+61kg-1	7552.000	98640	91088	D
50cm+121kg-1	8372.000	127520	119148	3421
30cm+61kg-1	8452.000	85930	77478	D
40+121kg-1	9372.000	116730	107358	D
50cm+182kg-1	10124.000	125160	115036	D
30cm+121kg-1	10172.000	91110	80938	D
40cm+182kg-1	10924.000	130770	119846	5173
30cm+182kg-1	11924.000	97580	85656	D
50cm+243kg-1	12076.000	112410	100334	D
40cm+243kg-1	12876.000	114670	101794	D
30cm+243kg-1	13676.000	89980	76304	D

Where,TVC=Totalvariablecost,MRR=Marginal RateofReturn,ETB=Ethiopianbirr.

CHAPTER5.CONCLUSSIONAND RECOMMENDATION

Conclusion

In this study, plant height, numberof branch per plant, number of pod per plant, numberof seed per plant, above ground dry biomass yield and adjusted grain yield of the tested crop were significantlyinfluenced by both the interaction effect of inter-row spacing and the blended NPS fertilizer rate. Nevertheless, the number of nodules, leaf area index, and harvest index were unaffected bythe interaction effect but were influenced bythe main effects of inter-rowspacing and blended NPS fertilizer rate. The tallest plant height (61.66 cm), maximum number of branches per plant (5.99), maximum number of pods per plant (18.40), maximum number of seeds per pod (8.23), highest above-ground dry biomass yield (6.10 t ha-^{1}), grain yield (4.59 t ha-^{1}) were recorded from a combined application of 40 cm inter-row spacing with 182 kg ha-^{1}of blend NPS fertilizer rate. The partial budget analysis revealed the highest net benefit(119,846 ETB/ha) with a marginal rate of return of 5173% was obtained when combining a 40 cm inter-row spacing with an application of 182 kg ha-^{1}of NPS fertilizer. Thus, it could be concludedthatcombined applicationof40cminter-rowspacingwith182kgha-1ofblendNPS fertilizer rate can be recommended to increase the productivityof haricot bean crop in the study area and areas with similar agro-ecology

Recommendation

Based the result of the present experiment combined application of 40 cm inter-row spacing with 182 kg ha-^{1} of blend NPS fertilizer rate gave the grain yield (4.59 t ha-^{1}) with highest net benefit (119,846 ETB/ha) with an acceptable marginal rate of return of 5173%. Therefore, this treatment can be recommended to increase the productivity of haricot bean crop in the studyarea and areas with similar agro-ecology. Based on this experiment the following research gaps were suggested for further research (i) the experiment needs to be repeated across locations and years as the experiment was conducted in specific area and in one growing season, soils and more varieties, (ii) continuous research on agronomic practices needs to be conducted.

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APPENDICES

Appendix Table 1.Mean square of analysis of variance (ANOVA) for days to 50% emergencyof haricot bean during 2023 cropping season.

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	0.347778	1.1039	0.3493	Ns
Inter-rowspacing	2	1.041111	3.3046	0.0556	Ns
BlendedNPS fertilizer	3	0.152222	0.4832	0.6974	Ns
Interaction	6	0.996667	3.1635	0.0216	Ns
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

Appendix Table 2.Mean square of analysis of variance (ANOVA) for days to 50% flowering of haricot bean during 2023 cropping season

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	0.645833	1.0446	0.3686	Ns
Inter-rowspacing	2	5.492500	8.8838	0.0015	***
BlendedNPS fertilizer	3	7.424722	12.0091	<.0001	***
Interaction	6	0.175833	0.2844	0.9381	Ns
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

AppendixTable3.Meansquareofanalysisofvariance(ANOVA)fordaysto90% physiological maturity of haricot bean during 2023 cropping season

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	2.33583	1.9538	0.1656	Ns
Inter-rowspacing	2	4.11750	3.4441	0.0500	*
Blended NPS fertilizer	3	28.72667	24.0284	<.0001	**
Interaction	6	0.50861	0.4254	0.8541	Ns
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

AppendixTable4.Meansquareofanalysisofvariance(ANOVA)fornumberofnodulesof haricot bean during 2023 main cropping season

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	0.373333	0.2904	0.7508	Ns
Inter-rowspacing	2	4.890000	3.8041	0.0381	*
BlendedNPS fertilizer	3	6.442593	5.0119	0.0085	**
Interaction	6	0.589259	0.4584	0.8313	Ns
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

Appendix Table 5.Mean squareofanalysis ofvariance(ANOVA)for Leaf areaindex ofharicot bean during 2023 main cropping season

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	0.007046	0.0137	0.9864	Ns
Inter-rowspacing	2	5.407714	10.4856	0.0006	Ns
BlendedNPS fertilizer	3	6.850682	13.2835	<.0001	Ns
Interaction	6	0.730492	1.4164	0.2529	Ns
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

AppendixTable6.Meansquareofanalysisofvariance(ANOVA)forplantheightofharicot bean during 2023 main cropping season

Source	DF	Meansquare	F-value	Pr >F	P-value
Replication	2	0.3878	0.1622	0.8512	Ns
Inter-rowspacing	2	268.4869	112.3281	<.001	**
BlendedNPS fertilizer	3	110.5522	46.2523	<.001	**
Interaction	6	39.9081	16.6965	<.0001	**
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

AppendixTable7.Meansquareofanalysisofvariance(ANOVA)fornumberofbranchper plant of haricot bean during 2023 main cropping season

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	0.474444	7.6126	0.0031	**
Inter-rowspacing	2	5.438611	87.2646	<.0001	**
BlendedNPS fertilizer	3	1.770000	28.4003	<.0001	**
Interaction	6	0.361944	5.8075	0.0009	***
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

AppendixTable8.Meansquareofanalysisofvariance(ANOVA)fornumberofpodperplant of haricot bean during 2023 main cropping season

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	0.19444	0.4533	0.6414	Ns
Inter-rowspacing	2	26.05528	60.7363	<.0001	***
BlendedNPS fertilizer	3	16.65657	38.8274	<.0001	***
Interaction	6	1.71491	3.9975	0.0074	**
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

AppendixTable9.Meansquareofanalysisofvariance(ANOVA)fornumberofseedperpod of haricot bean during 2023 main cropping season

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	0.001944	0.0214	0.9788	Ns
Inter-rowspacing	2	4.954444	54.6051	<.0001	**
BlendedNPS fertilizer	3	1.369630	15.0953	<.0001	**
Interaction	6	0.266296	2.9350	0.0294	*
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

AppendixTable10.Meansquareofanalysisofvariance(ANOVA)forbiomassyieldofharicot bean during 2023 main cropping season

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	0.007500	0.3653	0.6981	ns
Inter-rowspacing	2	2.743333	133.6236	<.01	*
BlendedNPS fertilizer	3	0.827778	40.3198	<.01	*
Interaction	6	0.105556	5.1415	0.19	*
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

AppendixTable11.Meansquareofanalysisofvariance(ANOVA)forhundredseedweightof haricot bean during 2023 main cropping season

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	2.10111	0.2728	0.7638	ns
Inter-rowspacing	2	2.47528	0.3213	0.7285	ns
BlendedNPS fertilizer	3	17.38324	2.2567	0.1101	ns
Interaction	6	3.11824	0.4048	0.8678	ns
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

AppendixTable12Meansquareofanalysisofvariance(ANOVA)forgrainyieldofharicot bean during 2023 main cropping season

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	0.0008528	0.8491	0.4413	ns
Inter-rowspacing	2	0.1045528	104.1059	<.0001	***
BlendedNPS fertilizer	3	0.0071000	7.0697	0.0017	***
Interaction	6	0.0140972	14.0370	<.0001	***
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

Appendix Table 13.Mean square of analysis of variance (ANOVA) for harvest index of haricot bean during 2023 main cropping season

Source	DF	Mean square	F-value	Pr >F	P-value
Replication	2	2.952	0.2096	0.8125	ns
Inter-rowspacing	2	1027.233	72.9552	<.0001	***
BlendedNPS fertilizer	3	286.233	20.3286	<.0001	***
Interaction	6	49.883	3.5427	0.1132	*
Error	22				

Where,***=veryhighlysignificantly(p<0.001),**=highlysignificantly(p<0.01),*=significant (p<0.05), ns=non-significant (p>0.05), DF=degree of freedom

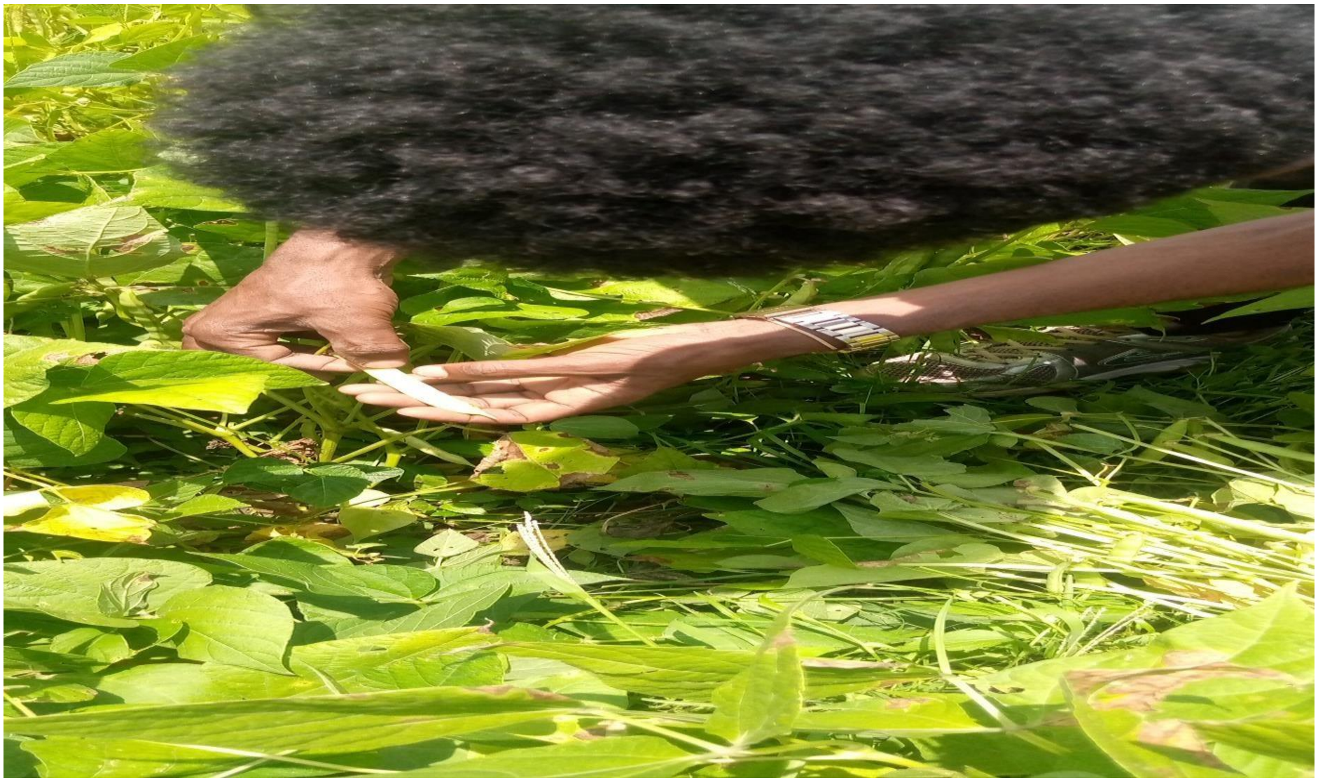
Appendix Figure

Appendixfigures1.Picturestakenduringexperimentalfieldobservationatmaturitystageof haricot bean (photo taken by the author, 2023).

Appendix figure 2.Pictures taken during data collection of plant height of haricot bean (phototaken by the author, 2023)

Appendix figure3.Picturestakenduringdatacollectionofnumberofbranchperplantofharicot bean (photo taken by the author, 2023)

Appendixfigure 4.Pictures taken during data collection of number of pod per plant of haricotbean (photo taken by the author, 2023)



Appendixfigure5.Picturestakenduringdatacollectionofnumberofseedperpodofharicot bean (photo taken by the author, 2023)

Appendixfigure6.Picturestakenduringdatacollectionofnumberofnodulesperplantof haricot bean (photo taken by the author, 2023)

BIOGRAPHY

The author, Zelalem Gedefaw was born in 21 November 1993 in East Gojjam zone at Hulet Eju Enesie Woreda particularly at Andnet Mariam Kebele in Amhara region, Ethiopia. He attended his elementary school at Keranyio primary school from 2003 to 2007. He completed his secondary and preparatory school education at Bahre Giorgis Secondary and Preparatory High School from 2008 to 2011. He joined Debre Markos University in 2012, college of agriculture and environmental resource and completed his study with Bachelor of Science in plant science in 14 June 2014. After his successful graduation, he was employed in one acre fund Ethiopia in 12 November 2015 and he has been served for three year in this institution. After this, he was employedinchokieFanaCollege asinstructorfrom2019to2022. InNovember2022,hejoined Bahir Dar University, college of agriculture and environmental science, school of post graduate programs to pursue his M.Sc. degree in agronomy.