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FDRE TECHNICAL & VOCATIONAL TRAINING INSTITUTE

FACULTY OF AGRICULTURE AND AGRO PROCESSING TECHNOLOGY

DEPARTMENT OF FRUIT AND VEGETABLES PROCESSING TECHNOLOGY

SCHOOL OF POST GRADUATE STUDIES

# Effect of Phosphorus Fertilizer Rates on Yield and Yield Components of Lentil Varieties (Lens Culinaris Medik.) In Adea District East Shewa Zone, Oromia National Regional State

M.SC. THESIS

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JUNE 2026

ADDIS ABABA, ETHIOPIA

FDRE TECHNICAL AND VOCATIONAL TRAINING INSTITUTE
SCHOOL OF POST GRADUATE STUDIES

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A THESIS SUBMITTED TO THE FDRE TECHNICAL AND VOCATIONAL TRAINING INSTITUTE SCHOOL OF GRADUATE STUDIES, FDRE TECHNICAL AND VOCATIONAL TRAINING INSTITUTE
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP PRODUCTION TECHNOLOGY

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# APPROVAL SHEET

I hereby certify that I have read and evaluated this thesis entitled "Effect of Phosphorus Fertilizer Rates on Yield and Yield Components of Lentil Varieties (Lens culinaris Medik.) in Adea District, East Shewa Zone, Oromia National Regional State," prepared under my guidance by Gemechis Desa Raje.

Therefore, I recommend to be submitted for defense as it fulfills the main thesis requirements.

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# CERTIFICATION SHEET

As thesis research advisor, I hereby certify that I have read and evaluated this thesis prepared under my guidance by Gemechis Desa Raje entitled “Effect of Phosphorus Fertilizer Rates on Yield and Yield Components of Lentil varieties (Lens culinaris Medik.) in Adea District, East Shewa Zone, Oromia National Regional State”. Therefore, I recommend to be submitted for defense as it fulfills the main thesis requirements.

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As members of the Board of Examiners of the M.Sc. Thesis Open Defense Examination, certify that we have read, evaluated the thesis prepared by Gemechis Desa Raje and examined the candidate. We recommend that the thesis be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Crop Production Technology.

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# DEDICATION

This thesis is dedicated to my beloved family and Bishoftu Agricultural Research Center, for their patience, encouragement and prayers during those difficult times, and for their wholehearted support in my life and success.

# STATEMENT OF AUTHOR

First, I declare that this thesis is a genuine result of my own work and I have duly acknowledged all sources of materials that I have used for writing this thesis. I have submitted this thesis in partial fulfillment of the requirements for the Degree of Master of Science at the FDRE Technical and Vocational Education Training Institute and deposited it in the University library to make it available to borrowers for reference under the rules and regulations of the library. I declare that this thesis was not submitted to any other institution anywhere for the award of any academic degree certificate.

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# BIOGRAPHYSKETCH

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# ABBREVIATIONS /ACRONYMS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| BARC | Bishoftu Agricultural Research Center |
| BNF | Biological Nitrogen Fixation |
| CSA | Central Statistics Agency |
| EIAR | Ethiopia Institute of Agriculture Research |
| ESHZANRO | East Shewa Zone Agriculture and Natural Resource Office |
| ETB | Ethiopian Birr |
| FAO | Food and Agriculture Organization |
| ICARDA | International Center for Agricultural Research in the Dry Areas |
| IMWIC | International Maize and Wheat Improvement Center |
| SAS | Statistical Analysis System |
| USDA | United States Department of Agriculture |

# ABSTRACT

Lentil (Lens culinaris Medik.) is an important legume crop in East Shewa Zone; however, its yield remains low mainly due to poor soil fertility management and the use of low-yielding local cultivars. A field experiment was conducted during the 2025main cropping season to evaluate the effect of Phosphorus fertilizer rates on yield and yield components of lentil Varieties in Adea District, East Shewa Zone in Oromia National Regional State. The study included four fertilizer levels (0, 23, 46 and 69 $P_2O_5$kg$^{ha-1}$), and four lentil varieties (Derso, Furi, Beredu and local cultivar). The two factors were factorially combined and laid out in randomized complete block design with three replications. Data analysis indicated that days to 50$^{\%}$ flowering, days to 90$^{\%}$ physiological maturity, nodulation, plant height, number of branches, pods per plant, thousand-seed weight, harvest index, and grain and straw yield were significantly affected by both main effects and two-way interactions. The highest number of total nodules (17.33), nodules fresh weight (56.15 mg), nodule volume (0.166ml) and number of effective nodules (16.00) were recorded from the application of 69kg $P_2O_5$ha-1 fertilizer with Varieties. In addition, the highest plant height (43.00cm), number of secondary branches per plant (9.22), thousand seed weight (28.00g), harvest index (42.99 %) and straw yield (4.84 t $^{ha-1}$) were recorded from the application of 69 kg $P_2O_5$ $^{ha-1}$ with the Derso variety. However, the highest number of pods per plant (65.00), dry biomass (52.57%) and seed yield (5.3 t/ha$^{-1}$) were recorded from application of 69 kg $P_2O_5$ $^{ha-1}$ with the Derso variety. Mean grain yield of lentil showed an increment by 70.32% with the application of 69 kg $P_2O_5$ ha-1 with Derso variety over the control (0 kg ha-1 $P_2O_5$with local cultivar). Application of 69 kg $P_2O_5^{ha-1}$ fertilizer with Derso variety gave higher net benefits of 1,238,020 EB ha$^{-1}$ with marginal rate of return of 14,300.00%. Therefore, the application of 69 kg $P_2O_5$ ha$^{-1}$ to the Derso variety to increase lentil production in the study area. However, further studies across multiple locations and seasons are required to validate these findings.



Keywords: Adea District; Derso; Economic analysis; Lentil (Lens culinaris Medik.);

Nodulation; Phosphorus fertilizer.

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# 1. INTRODUCTION

## 1.1. Background of the Study

Lentil (Lens culinaris Medik) is one of the most important pulse crops grown in Ethiopia. Lentil belongs to the genus Lens within the tribe Viceae of the family Fabaceae and is widely cultivated for human consumption and livestock feed (Wang, 2012). It is an important cool-season food legume crop in Ethiopia and is considered vital to food and nutritional security.

Ethiopia is the leading producer of lentil in Africa followed by Morocco, Tunisia and eleventh in the world (Zeroual et al., 2024). In Ethiopia, lentil covers 69.4% of the area, which accounts for about 81.5% of the total production in Africa(Zeroual et al., 2024). Lentil is a popular ingredient in everyday diets in the majority of households in Ethiopia; and it is used in “Misir wot” and in soup from whole seeds or flour. It provides affordable source of dietary proteins, minerals, fiber, and carbohydrates to the people in developing countries (Zeroual et al., 2024).

According to CSA (2018) in Ethiopia about 119,046 ha of land is cultivated with lentil, which accounts for 1,751,435.58 quintals with a productivity 1471 kg ha-1. While in Oromia Region about 42,743.74 ha of land is cultivated with a lentil and accounts for 706,006.25 quintals with a productivity 1652 kg ha-1. Similarly, ESHZANRO (2018) reported that about 9,353.5 ha of land was cultivated with lentil, which produced 100,377 quintals with a productivity of 1073 kg ha-1. At the study, area about 604.75 ha of land is cultivated with a lentil with a production of 4,622 quintals and with a productivity of 664 kg ha-1 (ADANRO, 2018). This indicated that the average lentil productivity at Zonal and District levels were still below the regional level of lentil productivity. Lack of optimum rates and appropriate fertilizer types (P) application for lentil production is the main constraints that limit lentil productivity in the study area. Poor agronomic practices applied to lentil production are also other causes for low productivity of lentil (Getahun, 2016; Wondwosen et al., 2016). Moreover, lack of improved lentil variety causes crop susceptibility to insect pests and diseases, which resulted in low productivity of lentil. Lentil has relatively high requirement for phosphorus to promote root growth and vigorous seedlings (Getahun, 2016). Phosphorus encourages vigorous root growth, which is an

important step in the nitrogen-fixation process through promoting nodule development. Even though it plays a great role in crops growth and development in the central highlands of Ethiopia, about 70 to 75% of the agricultural soils deficient in phosphorus (Gifole et al., 2021; Azmera, 2017). To overcome these problems, the application of optimum phosphorus fertilizer can be a solution to improve lentil productivity.

It is also an export and cash crop with the highest price in domestic and international markets for Ethiopia. Lentil is, grown in rotation with cereals to break cereal disease cycles and to fix atmospheric nitrogen(Yadav et al., 2026).

## 1.2. Statement of the Problem

The average grain yield of lentil (1471 kg ha-1) in Ethiopia is very low compared with the global potential yields 2800 $kg^{ha-1}$ (CSA, 2018). The low lentil productivity in Ethiopia is due to use of predominantly local cultivars, poor soil fertility and limited agronomic practices(López-Calabozo et al., 2024). Despite its importance, lentil productivity in the Adea district, like many parts of Ethiopia, remains low. One of the major abiotic constraints contributing to this low yield is declining soil fertility, particularly phosphorus deficiency(Niri et al., 2010)(Dinssa & Elias, 2021).

Ethiopian soils, especially Vertisols and Nitisols common in lentil growing areas like Adea, are often characterized by low available P due to high P-fixation capacity, continuous cropping without adequate Phosphorus replenishment, and soil erosion(Dinssa & Elias, 2021).According to (Bezabeh, 2017) report no or low rate of $P_2O_5$ $^{ha-1}$ of fertilizer application, lack of improved lentil seed variety, lack of access and awareness of bio fertilizers usage for lentil, susceptibility of lentil to different stresses and low genetic yielding potential of land races are the main constraints that limit the lentil productivity at the study area.

Similarly, Feleke et al., (2021) reported that the consumption of lentil is decreasing mainly because of the high level of limiting factors on its production and productivity in Ethiopia.

The yield-limiting factors include cultivation of local varieties for long period, inappropriate seedbed preparation, poor field management, use of unhealthy seed, lack of seedling vigor, high rate of flower drop, low pod setting, low yield, low or no

response to inputs, and subject to various biotic and abiotic stresses. Therefore, although some yield response with application of fertilizer along with varieties have been, reported in different regions in country. So far, few works have been, conducted on determination of optimum $P_2O_5$fertilizer rate for production of lentil at the study area.

Hence determining the optimum rates of $P_2O_5$ fertilizer with better performing genotype of lentil have a paramount significant for the improving the productivity of lentil in the study area.

## 1.3. Objectives

### 1.3.1. General Objective

To improve production and productivity of lentil Varieties (Lens culinaris Medik.) through use of appropriate rates of phosphorus fertilizer in the central high land of Ethiopia.

### 1.3.2. Specific Objectives

To evaluate the effect of phosphorous fertilizer rates on yield and yield components of lentil in Adea district.

To determine the economically optimal level of phosphorus fertilizer rates for lentil production in Adea district.

# 2. LITERATURE REVIEW

## 2.1. Origin and Distribution of Lentil

Legumes (family Fabaceae) are among the most widely distributed plant families in the world, consisting of hundreds of genera and thousands of species grown across different continents (Hughes et al., 2025). Lentil is believed to have originated in Western Asia and was domesticated thousands of years ago before spreading to the Indo-Gangetic plains around 2000 BC (Cubero, 1981). From its center of origin, lentil gradually expanded to Egypt, the Mediterranean region, Central and Southern Europe, Ethiopia, Afghanistan, Pakistan, China and later to the Americas, including Mexico, Chile, Argentina and Canada (Guerra-Garcia et al., 2022).

Today, lentil is cultivated globally, with Canada, India, Turkey, Australia, the USA, Nepal, China and Ethiopia being major producers. Canada and India currently contribute the largest share of global production (FAOSTAT, 2020; Guerra-Garcia et al., 2022).

The wide geographical adaptation of lentil demonstrates its importance as a food and cash crop in both developed and developing countries.

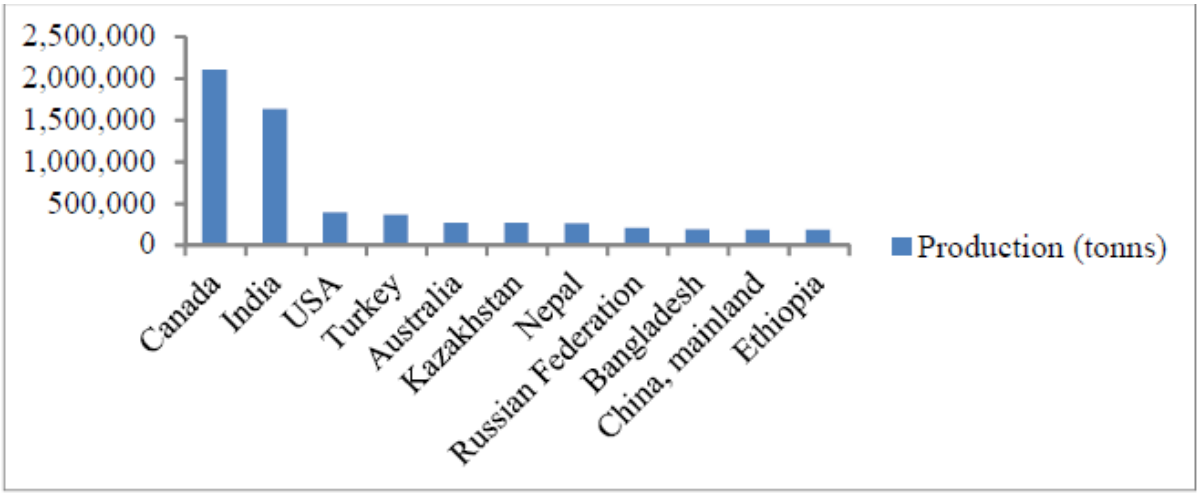



Figure 1: Global Major Lentil Producing Nations In Metric Tons In 2018

Source: FAOSTAT (2020)

## 2.2. Botanical Description of lentils

Lentil (Lens culinaris Medik.) belongs to the genus Lens within the tribe Viceae of the family Fabaceae (Kumar et al., 2024). Two main cultivated types exist small-seeded

types (microsperma) and Large-seeded types (macrosperma) (Palacios et al., 2023). Lentil is an annual herbaceous plant characterized by slender stems and a bushy growth habit. The crop usually grows to about 40 cm in height and produces pods containing one or two lens-shaped seeds (Vijayaraje et al., 2022). Lentil plants exhibit indeterminate growth, meaning vegetative and reproductive growth may occur simultaneously, which makes nutrient availability particularly important during the growing season (Maphosa et al., 2023).

Lentil belongs to the genus Lens of the Viceae tribe in the Legumnosae (Fabaceae) family, commonly known as the legume family. The plant was given the scientific name Lens culinaris in 1787 by Medikus, a German botanist and physician (Kumar et al., 2024).The cultivated lentil Lens culinaris spp. Culinaris, has two varietal types: small seeded (microsperma) and large seeded (macrosperma)(Palacios et al., 2023). It is an annual bushy herb with slender stem and having many branches with erect, semi-erect or spreading growth habit. Lentil is a bushy annual pulse crop cultivated primarily for its lens-shaped seeds. It is about 40 cm (16 in) tall and the seeds grow in pods, usually with two seeds in each (Vijayaraje et al., 2022). The cotyledons remain under ground after germination.

The first two nodes on the stem develop below, or at the soil surface and are known as scale nodes. Plants can have single stems or many branches depending upon the population in the field. Lentil plants have an indeterminate growth habit (Maphosa et al., 2023). Flowering begins on the lowest branches; gradually moving up the plant and continuing until its physiological maturity. Lentil continue to flower until they encounter some form of stress, such as drought, heat, frost, nitrogen deficiency, mechanical damage, or chemical desiccation(Zeroual et al., 2023). This indeterminate growth habit is most predominant in late maturing varieties.

## 2.3. Importance of lentil productions

Lentil (Lens culinaris Medik) is one of the most important pulse crops in Ethiopia, playing a major role in household food security, soil fertility improvement, and income generation. Recent global reports indicate that pulses contribute significantly to sustainable agriculture due to their ability to fix atmospheric nitrogen and reduce

dependence on synthetic fertilizers (FAO, 2023).

Ethiopia is among the leading lentil producers in Africa, and lentil is widely cultivated in the highlands where it serves as both a food and cash crop.

Despite its importance, national average yields remain far below the crop's potential due to poor soil fertility and inadequate fertilizer management (Alem et al., 2021).

Lentil is the very important pulse crop grown in Ethiopia in order to meet the export and domestic needs. It provides important economic advantages to the small-scale farm households in providing food, feed, cash income and foreign currency earnings. It provides affordable source of dietary proteins, minerals, fiber, and carbohydrates to the people in developing countries(Varghese et al., 2019).

It is also an export and cash crop with the highest price in domestic and international markets for Ethiopia (Getachew, 2019).Lentil is, grown in rotation with cereals to break cereal disease cycles and to fix atmospheric nitrogen(S. Kumar et al., 2019). Lentil is the most important crop because of its high protein content and fast cooking characteristic (Dhull et al., 2023).

The nutritional characteristics of lentil have been associated with cholesterol and lipid lowering effects in humans, along with reducing the incidence of colon cancer and diabetes. It provides affordable source of dietary proteins (22–35%), minerals (iron, cobalt and iodine) and vitamins, fat (1-2%) crude fiber (4.6%), starch (44.3%), amylose (36.1%) and (63.1 %) of total carbohydrates to poor people and plays a vital role in alleviating malnutrition and micronutrient deficiencies in developing countries(Alexander et al., 2024).

Lentil is an excellent source of easily digestible protein, lower in anti-nutritional factors i.e. hem agglutinins, oligosaccharides and flavones compared to other legumes (Li et al., 2024). It is a rich source of minerals containing 68 mg calcium, 300 mg phosphorus and 7 mg iron per 100 g lentil seed(DÜZGÜN et al., 2022).

Similarly, (Aghababaei et al., 2024)reported that lentil seeds contain high levels of protein, including the essential amino acids isoleucine and lysine, and unlike meat, poultry, fish and eggs, this protein source contains no cholesterol and virtually no fat. Lentil, eaten with a grain such as rice, wheat or barley, provides all the essential amino acids required by the human body in a balanced diet.

Legume straw generally has higher nutritional quality than cereal straw., because

they have higher nitrogen contents, greater voluntary intake and faster ruminal degradation(Aghababaei et al., 2024) . Lentil straw was nutritionally superior to wheat straw in its protein, Ca and P contents and it has high digestibility due to supplementation of critical nutrients, which diverted rumen fermentation in a favorable direction. The improvement of digestibility in the rumen may be due to the supplementation of critical nutrients, with lentil straw, which diverted rumen fermentation in a favorable direction(Pugliese et al., 2024).

Role of phosphorus in crop production

Phosphorus is an important macronutrient necessary for plants' growth and development. Phosphorus is vital in Energy transfer (formation of ATP), Photosynthesis and respiration, Root development and Blossoming and seed formation. Proper amounts of phosphorus ensure rapid growth of plants, better root growth, and improved nodule formation in legumes. This, in turn, boosts crop productivity and yield. In several tropical regions, such as Ethiopia, phosphorus is not abundant because of its strong fixation to soil minerals. Therefore, crop productivity can be enhanced through phosphorus application.

Phosphorus fertilization is crucial for enhancing lentil (Lens culinaris) yield and increasing farm profitability. Utilizing the appropriate quantity of phosphorus typically about 40–60 kg $P_2O_5$ per hectare can significantly enhance pod development, seed production, and overall profits, especially in soils lacking phosphorus. In numerous instances, effective phosphorus management can increase net profits by 20–30%. Sufficient phosphorus promotes root growth and improves nodulation, which aids in effective biological nitrogen fixation. This results in increased seed and stover production.

Studies consistently indicate that applying around 40–60 kg $P_2O_5$ per hectare yields the optimal economic return, whereas increased rates might result in only minimal extra benefits. Applying phosphorus enhances plant height, branching, and dry matter production, all of which lead to higher seed yield and better benefit-cost ratios. Phosphorus is crucial for the development of root nodules and the process of nitrogen fixation, aiding in less dependence on synthetic nitrogen fertilizers and decreasing production expenses. It also enhances seed protein levels, potentially increasing market worth. Since numerous soils where lentils are cultivated possess

low to moderate levels of phosphorus, applying phosphorus fertilizer is frequently the most economical nutrient investment.

Administration for Optimal Profits because phosphorus travels slowly through the soil, applying it during planting or as an initial fertilizer enhances absorption efficiency.

Yield and profitability can be enhanced by pairing phosphorus with nitrogen (for instance, 40 kg N together with 40–60 kg $P_2O_5$ per hectare) or Sulphur (approximately 30 kg per hectare).

In general, proper phosphorus management is crucial for enhancing lentil yields, elevating crop quality, and raising farmers' net earnings, particularly in soils lacking phosphorus although phosphorus fertilizer increases yield, its economic profitability depends on the balance between input cost and yield gain. Partial budget and marginal rate of return analyses are commonly used to determine economically optimum fertilizer rates for farmers.

## 2.4. Lentil production in Ethiopia

In low-income countries, the agricultural sector is essential to growth, poverty reduction, and food security. Pulse crops are important components of crop production in Ethiopia's small-holders agriculture, providing an economic advantage as an alternative source of protein and other nutrients, cash income, that seeks to address food security (Andarge, 2023).

In Ethiopia, lentil is one of the 12 important food legumes mainly cultivated by smallholder farmers in cooler Central and Northern highlands(Melese et al., 2025). Small-scale farmers in Ethiopia grow various crops for their own consumption purposes and economic benefits.

Lentil provides important economic advantages to the small-scale farm households in providing food, feed, cash income and foreign currency earnings. Pulses are among the crops produced in all region of the country following the cereals in terms of total production and area coverage. Lentil is, grown on small-scale farms as a food and cash crop in Ethiopia. Lentil is largely grown on black Vertisols, which often suffer from inadequate drainage during the main rainy season (June-August).

Consequently, lentil is planted late in the season (September-October) on residual moisture. On well-drained black soils, lentil and chickpea could be grown as a second crop after cereal crops like barley(Melese et al., 2025).

Lentil Improved Varieties Released in Ethiopia

Variety itself is the genetical factor, which contributes a lot for producing growth, yield and yield components. Lentil research was formally started in 1972 and about 11 lentil varieties were released by both national and regional research center ( G. Kebede & Mohammed, 2019). Some of these varieties are rust resistance and high yielder than the local cultivars. Crop rotation and the use of improved seeds will positively affect lentil yield (Roy et al., 2023). According to (G. Kebede & Mohammed, 2019) there is significant variation among lentil germ plasm for most of the traits (Table 1). The existence of phenotypic diversity in Ethiopian lentil varieties gives high opportunity for genetic improvements. Lentil varieties significantly varied for days to flowering, days to maturity, plant height, and number of primary branches per plant, pods per plant, seeds per pod, grain yield, and 100 seed weight.

Derso (1121), Danbi (1094) and Alemaya (1024 kg ha-1) had a maximum mean grain yield (Yirga and Zinabu, 2018). The mean for days to flowering of tested varieties ranged from 42 days to 77.3 days while days to maturity for tested variety ranged from 104 days to 133 days that showing highly significance difference among the tested varieties (ICARDA, 2016). Except 90% emergence most Phenological traits (days to flowering, and days to maturity), biomass yield, grain yield and yield components and plant height were significantly, affected by varieties (Naik et al., 2024). Early maturing varieties complete their life cycle in relatively shorter period. Thus, early maturing varieties have advantage over the late maturity ones in environments where rain begins late and ends early. (Mukherjee et al., 2023) also reported that most of the recently released varieties provide a higher biomass production rate and seed growth rate than the older varieties.

Ethiopia is one of the largest producers of lentils in Africa. The crops thrive under cool climates and moderate rainfall within the highlands and mid-highlands of Ethiopia. Lentils are considered an important source of income for small-scale

farmers through exports. However, despite the significance of this crop, productivity is hindered by low nutrient levels, acidic soil conditions, improper use of fertilizers, and lack of adoption of technology.

Lentil (Lens culinaris Medik) is one of Ethiopia's most important pulse crops, with strong roles in food security, nutrition, soil fertility, and income generation.
Ethiopia is widely considered a center of diversity and one of Africa's major lentil producers, especially in the highlands of Oromia, Amhara and Tigray.

Table 1. Some Lentil varieties released in Ethiopia

| No | Varieties | Year of released | 100SW(gm) | Seed yield(q $ha^{-1}$) | | Seed color | Adaptation | |
|---|---|---|---|---|---|---|---|---|
| | | | | Farmer field | Research | | Altitude (m) | Rain fall (mm) |
| 1 | EL-142 | 1980 | 2.4-2.5 | 9-12 | 14-20 | Brown | 1650-2000 | 400-600 |
| 2 | R-186 | 1980 | 2.6-2.9 | 14-16 | 17-25 | Green | 1800-2400 | 500-120 |
| 3 | Chalew | 1985 | 2.6-3.1 | 14-18 | 19-26 | Yellow | 1850-2450 | 500-1200 |
| 4 | Chekol | 1994 | 2.2-2.4 | 14-16 | 15-22 | Grown | 1600-2200 | 400-600 |
| 5 | Gudo | 1995 | 4.4-6.1 | 14-18 | 18-25 | Redish- Brown | 1850-2450 | 500-1900 |
| 6 | Adaa | 1995 | 3.3-4.2 | 16-24 | 19-26 | Grey | 1850-2450 | 500-1100 |
| 7 | Alemaya | 1997 | 2.7-3.3 | 18-24 | 20-30 | Yellow-Redish | 1650-2600 | 450-1200 |
| 8 | Alem Tena | 2003 | 2.9-3.9 | 14-18 | 17-23 | Grey | 1600-2400 | 400-600 |
| 9 | Teshale | 2003 | 3.1-4.1 | 16-26 | 18-31 | Grey | 1800-2400 | 400-800 |
| 10 | Jiru | 2015 | 3.3-3.6 | 18-28 | 26-33 | Light green | 2600-2700 | 900-1100 |
| 11 | Dembi | 2013 | 2.8-3.2 | 12-20 | 17-25 | Golden | 1800-2400 | 600-700 |
| 12 | Derash | 2010 | 3.2-3.7 | 20-30 | 23-37 | Yellowish | 1600-2400 | 400-800 |

Source: -EIAR (2006); Nigussie and Abiro (2019)

## 2.5. Major Lentil Production and Productivity Constraints in Ethiopia

In spite of its importance, lentil productivity has remained very low mainly due to the use of low yielding local cultivars, biotic and abiotic constraints, and poor management practices. There has been a high degree of risk in pulses production in general and lentil production in particular(Feleke et al., 2021). Biotic and abiotic as

well as economic constraints affect the lentil production at different stage and in different ways. I.e. Lack of knowledge, non-availability of improved seed, poor technical guidance was few socio economic that can affect the lentil production. The average productivity of lentil in West Asia, North and East Africa is low due to use of predominantly local cultivars(Feleke et al., 2021). Local cultivars have limited yield potential and are vulnerable to an array of stresses.

The yield limiting factors are lack of seedling vigor, slow leaf area development, high rate of flower drop, low pod setting, poor dry matter, low harvest index, lack of lodging resistance, low or no response to inputs, and subject to various biotic and abiotic stresses(E. Kebede, 2020).

### 2.5.1. Abiotic Constraints

Abiotic stress is a broad term, which includes multiple stresses such as heat, chilling, excessive light, drought, water logging, ozone exposure, osmotic shock and salinity. Lentil production and productivity can be, affected by different abiotic stresses such as terminal drought, heat stress; salinity, cold, waterlogging and low soil fertility Zeroual et al., (2023). Drought, salinity, waterlogging and frost have impact on the rain-fed lentil production culture of the Ethiopia. There is more than 50% loss due to these factors where the situation is severe Zeroual et al., (2023).

Similarly, Zeroual et al., (2023) reported that the impact of moisture stress depends on its severity and duration; prevents the crops from reaching the maximum yield. According to these authors nitrogen fixation, uptake and assimilation by leguminous plants are reduced due to the reduction in leghaemoglobin in nodules and the number of nodules under moisture-stress conditions.

Flooding may increase the incidence of soil-borne fungal diseases besides converting $SO4_2$- to $H_2S$ by anaerobic bacteria. Under waterlogging, growth is arrested and death takes place principally because demand for Adenosine triphosphate (ATP) molecules exceeds the supply and self-poisoning by products of anaerobic metabolism (Dhull et al., 2023).

The reduction in mean seed weight and number of flowers per plant observed in pea and faba bean was probably due to a decrease in photosynthesis and nitrogen supply to seeds (BNF and N remobilization) during seed filling, both resulting from

reduced shoot and nodulated root growth(Li et al., 2024).

Similarly reported that chickpea root growth, nodulation, shoot growth, yield, yield components, harvest index and stomatal opening significantly affected due to waterlogging(Zeroual et al., 2023). At flowering phase of chickpea, it caused large flower abortion, severe root and nodule degradation, shortened seed filling duration and detrimental leaf. Water logging at flowering affected grain yield most adversely and caused losses 95% to 99% based on chickpea genotypes. Salinity also highly affects growth, yield and yield components of crops. Reduction of germination percentage, shoot and root length, shoot/root ratio, yield and yield components of lentil were observed due to salinity effect (Geja, 2020).

### 2.5.2. Biotic Constraints (Diseases and Insect pests)

In many countries, lentil is cultivated as a rain fed crop and affected by several biotic factors (fungi, viruses, nematodes, insect pests and parasitic plants)(Sharma & Muniappan, 2021). This can be due to use of local cultivars, which are vulnerable to an array of stresses (Singh Ahlawat et al., 2022). Some of the more serious problems lentil dieses are; Root rot/wilt complex (caused by Pythium, Rhizoctonia, Sclerotium, and Fusarium species), Rust (caused by Uromyces Viciae-fabae Pers), Ascochyta blight (caused by Ascochyta fabae) and Botrytis grey mould (Botrytis cinerea) (Tolesa Bedasa, 2018).

Green pea aphids, and in some cases, trips are among the most important insect pests affecting lentil production. There is about 30% yield loss due to aphid infestation Fakhouri et al., (2021). Aphids damage lentil directly by feeding it and more seriously transmit plant viruses. Both nymphs and adults suck the plant saps from the tender leaves, stems and pods. In addition, mostly colonize on the young leaves and growing points, which become characteristically deformed. This prevents normal plant growth and affects the yield.

## 2.6. Climate and Soil Requirement

Lentil (Lens culinaris Medik.) is one of the less selective legumes in terms of climate and soil features. It can be grown to an altitude of 3000 meters (Kar et al., 2022). Lentil is among the principal food legumes widely grown in diverse agro-ecological

zones, ranging from hot sub-moist low lands to cool humid mid highlands (Andarge, 2023).Young plants are tolerant of spring frosts and this allows for early spring planting dates.

Lentil requires cool conditions during vegetative growth and relatively warm temperatures during maturation. The optimum temperature for growth is 18-30$^{0}$C (Kar et al., 2022). Lentil can grow on a wide range of soils, from sandy to clay loam, provided that drainage is adequate. It does not tolerate flooded or waterlogged soils, and does best on deep, sandy loam soils high in phosphorus and potassium. Good drainage is required, because even short periods of exposure to waterlogged or flooded field conditions kill plants.

Although it performs best on level or slightly rolling land at a soil pH of 6.0 to 8.0 lentils adapted to all soil types, from sand to clay loam, if there is good internal drainage. Lentil do not grow well on waterlogged soils and will not tolerate flooding or salinity (Geja, 2020).

Cropping Systems and Agricultural Values of Lentil

In crop rotations on organic farms, yields depend both on the optimization of the N inputs and reduction of nutrient losses (Diacono et al., 2019).

Legumes are important components in farming systems, providing environmental and ecological benefits through crop rotation, especially by contributing to soil fertility and rhizosphere diversity through biological nitrogen fixation (Khazaei et al., 2016).

Lentil is among the most important cool season food legumes cultivated in rotation with cereal crops in most parts of the country to break cereal disease cycles and to maintain soil nitrogen, thus reducing the demand of other cereal crops for nitrogen fertilizers(S. Kumar et al., 2019). He further stated lentil can be, grown in rotation to cereal crops, which promote sustainable cereal-based production systems with a potential of fixing free nitrogen reached up to 107 kg ha-1. Increasing lentil production has a significant role in improving Ethiopia’s economy and maintaining soil fertility (Fikre, 2023).

Nitrogen fixation capacity of lentil is significantly higher when grown in intercropping with other legume species than mono cropping. Legumes can symbiotically fix atmospheric N through Rhizobia and therefore need minimal fertilizer N

applications.

## 2.7. Effect of phosphorus on Phenological Parameters

Phenology describes the timing of biological events in a plant's life cycle. In lentils, Phenological parameters such as days to 50% emergence, 50% flowering, and 90% physiological maturity are crucial for determining the adaptation of a variety to a specific agro-ecology and the length of the growing season.

Days to 50% Emergence: - While primarily influenced by soil moisture and temperature, seed vigor enhanced by phosphorus nutrition plays a role. Phosphorus is vital for root growth and energy metabolism during germination. Abera et al. (2021) noted that seeds treated with adequate phosphorus often exhibit more vigorous early growth, leading to uniform emergence. However, the direct effect of applied P fertilizer on days to emergence is sometimes minimal compared to its effect on later stages, unless the soil is severely P-deficient, which slows radicle elongation.

Days to 50% Flowering

Flowering is a critical transition stage from vegetative to reproductive development. Phosphorus is known to accelerate flowering because it is involved in ATP (adenosine triphosphate) production, which powers the energy-intensive process of reproductive initiation. Tadesse et al. (2021) reported that increasing phosphorus rates up to an optimal level significantly reduced the number of days to 50% flowering in lentils. This early flowering is advantageous in areas like the Adea District, where terminal moisture stress can occur at the end of the season, allowing the crop to mature before the soil dries out.

Days to 90% Physiological Maturity

Physiological maturity indicates when the pods have reached their maximum dry weight and the crop is ready for harvest. Similar to flowering, adequate phosphorus supply tends to hasten maturity. Gezmu and Bekele (2022) observed that lentil plants supplied with sufficient P fertilizer reached 90% physiological maturity earlier than those in the control plots. This is attributed to the efficient metabolic processes facilitated by P, which allow the plant to complete its life cycle faster. Delayed maturity in Low-P conditions can expose the crop to late-season pests and drought

risks.

## 2.8.Effect of phosphorus on Growth Parameters

Growth parameters determine the canopy structure and the photosynthetic capacity of the plant, which are prerequisites for high yield.

Plant Height

Plant height is a function of internode elongation and is directly influenced by phosphorus availability. Phosphorus promotes cell division and elongation. Amare et al. (2023) conducted a study in the central highlands of Ethiopia and found a significant linear relationship between P fertilizer rates and plant height. Taller plants are generally associated with better competition against weeds and higher biomass potential, provided they do not lodge.

Number of Primary and Secondary Branches

Branching is essential for increasing the number of potential fruiting sites on a lentil plant. Primary branches arise from the main stem, while secondary branches arise from primary branches.

Primary Branches: Research by Worku and Tesfaye (2020) indicates that P application significantly increases the number of primary branches. Robust root systems supported by P enable the plant to support more vegetative growth.

Secondary Branches: The effect on secondary branches is often even more pronounced. Kefyalew et al. (2022) reported that higher P rates encouraged the development of secondary branches, which directly contribute to pod bearing. Increased branching improves the plant's architecture for light interception, thereby boosting photosynthesis.

## 2.9. Effect of phosphorus on Nodulation Parameters

Lentil forms a symbiotic relationship with Rhizobium bacteria to fix atmospheric nitrogen. Phosphorus is critical for this symbiotic process.

Total Number of Nodules and Effective Nodules

Nodules are the sites of nitrogen fixation.

Total Nodules: P promotes root growth and root hair formation, increasing the sites

available for bacterial infection. Bulti and Asefa (2020) reported a significant increase in the total number of nodules per plant with increasing P rates.
Effective Nodules: Not all nodules are functional; effective nodules contain leghemoglobin (giving them a pink/red interior) and actively fix nitrogen. P deficiency leads to many small, ineffective (white/green) nodules. Assefa et al. (2021) emphasized that P fertilization increases the proportion of effective nodules, as the energy requirement for nitrogen fixation is high and must be met by P-energized ATP.
Nodule Fresh and Dry Weight
Nodule weight is often a better indicator of nitrogen fixation potential than nodule count alone. Larger, heavier nodules generally have more nitrogenase activity. Fikre and Hailu (2022) observed that both nodule fresh weight and dry weight increased significantly with the application of phosphorus. This increase correlates with the plant's need for more nitrogen to support the enhanced vegetative growth stimulated by P.
Volume of Nodules
Nodule volume is a physical measure of nodule size. Larger nodule volume implies a larger surface area for the exchange of nutrients and gases between the plant and the bacteria. Recent research by Chanie and Abdeta (2023) indicated that phosphorus application significantly increased nodule volume. This expansion is associated with the active division of nodule cells and the proliferation of bacteroids, which are both energy-dependent processes fueled by phosphorus.

Phosphorus (P) is a fundamental nutrient for legumes like lentils (Lens culinaris), playing a critical role in the formation, activity, and efficiency of nitrogen-fixing root nodules. At a physiological level, phosphorus facilitates essential metabolic functions such as energy transfer and nucleic acid synthesis which are vital for robust root and nodule development.
Research consistently demonstrates that adequate phosphorus availability improves nodulation characteristics. Well-fertilized plants develop stronger root systems that support a higher quantity of large, highly active nodules, leading to superior nitrogen fixation (Sonet et al., 2020). This creates an optimal environment for the symbiotic

relationship between the plant and rhizobia bacteria. Consequently, phosphorus-fertilized lentils exhibit higher nitrogen fixation capacities, which translates directly into enhanced growth and higher crop yields (Melese et al., 2025). However, fertilization requires careful balance, as excessive phosphorus application can cause nutrient imbalances that ironically inhibit nodule formation (TUNÇ & RUFAİOĞLU, 2024).

Phosphorus and Symbiotic Nitrogen Fixation: Phosphorus plays a crucial role in the symbiotic relationship between lentil plants and rhizobia bacteria. Rhizobia form nodules on the roots of legumes and fix atmospheric nitrogen, which the plant uses for growth. Adequate phosphorus enhances the efficiency of this process by improving the overall health of the plant and its rhizobia.

Increased Nitrogen Fixation: Studies have shown that the application of phosphorus fertilizer increases the nitrogen fixation capacity of lentils by enhancing nodule formation and function. (Melese et al., 2025)observed that phosphorus-fertilized

## 2.10. Effect of phosphorus on Yield and Yield Component Parameters

### Yield and Yield Components

Yield components are the individual quantitative traits that contribute to the final grain yield.

Number of Pods per Plant

This is often the most yield-determinant component in lentils. Since phosphorus is vital for flower initiation and reduces flower abortion, it has a direct positive correlation with pod number. Gebremedhin et al. (2023) found that as P rates increased, the number of pods per plant increased significantly, owing to the enhanced branching and reduced flower drop caused by improved carbohydrate availability.

Number of Seeds per Pod

While largely a genetic trait, seed number per pod can be influenced by environmental factors and nutrition. P ensures efficient energy transfer during pollination and seed set. Duguma and Ejeta (2023) observed that lentils grown with optimal P fertilization produced a higher number of seeds per pod compared to those under P deficiency, as the latter suffered from poor pollen viability and

fertilization.

Dry Biomass and Straw Yield

Biomass accumulation represents the total vegetative and reproductive dry matter. Straw yield is the residue left after threshing. Phosphorus application increases total dry matter production by enhancing canopy development and leaf area index. Abdeta et al. (2020) demonstrated significant increases in both total above-ground dry biomass and straw yield with increasing P rates. High straw yield is also beneficial for livestock feed in mixed farming systems like those in East Shewa.

Grain Yield

Grain yield is the economic product and the integration of all components. Numerous studies confirm that P is the most limiting nutrient for legume production in Ethiopian soils. Alemayehu and Sheleme (2022) reported that applying 46 kg $P_2O_5$ $ha^{-1}$ increased grain yield by over 50% compared to the unfertilized control. The yield increase is attributed to the synergistic effects of P on root growth, nodulation, and the subsequent increase in pods and seeds per plant.

Thousand Seed Weight (TSW)

Thousand seed weight reflects the size of the seed and the filling efficiency. It is a stable yield component but can be improved by better nutrition. Phosphorus facilitates the translocation of photosynthates (sugars) from the leaves to the developing seeds. Tolera and Chemeda (2021) noted that P fertilization resulted in heavier seeds (higher TSW), which improves market quality and seedling vigor for the next generation.

Harvest Index (HI)

Harvest Index is the ratio of grain yield to total above-ground biomass. It measures the economic efficiency of the crop. Phosphorus application generally improves HI because it helps partition assimilates into the reproductive organs rather than just vegetative growth. Nigussie et al. (2023) found that lentil varieties supplied with P had a significantly higher harvest index, indicating efficient dry matter partitioning into grain.

## 2.11. Interaction of phosphorus with lentil varieties

Improved lentil varieties often respond differently to phosphorus fertilization due to

genetic differences in nutrient use efficiency. Modern varieties typically exhibit, Better nutrient uptake efficiency, Improved assimilate partitioning and higher yield potential Studies have shown that combining improved varieties with appropriate phosphorus rates results in higher productivity than using either practice alone. This highlights the importance of integrated crop management.

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# 3. MATERIALS AND METHODS

## 3.1. Description of the Study Area

A field trial was conducted during 2025 in Adea district (Bishoftu Agricultural Research Center) (during Mid-July) under rain fall conditions. Bishoftu Agricultural Research Center is located at an altitude of 1900 m above sea level, 47 km east of Addis Ababa and at a Latitude and Longitude of $8^0$ 41'36" N and $39^0$ 3'17" E, respectively. The maximum and minimum temperatures of the area are 27 and 15 $^0$C, respectively, the mean annual rainfall is 700-900 mm and the majority of the Adea district soil is heavy soils (Vertisols) with few pockets of light soils (Alfisols/ Mollisols) (WRB, 2006).

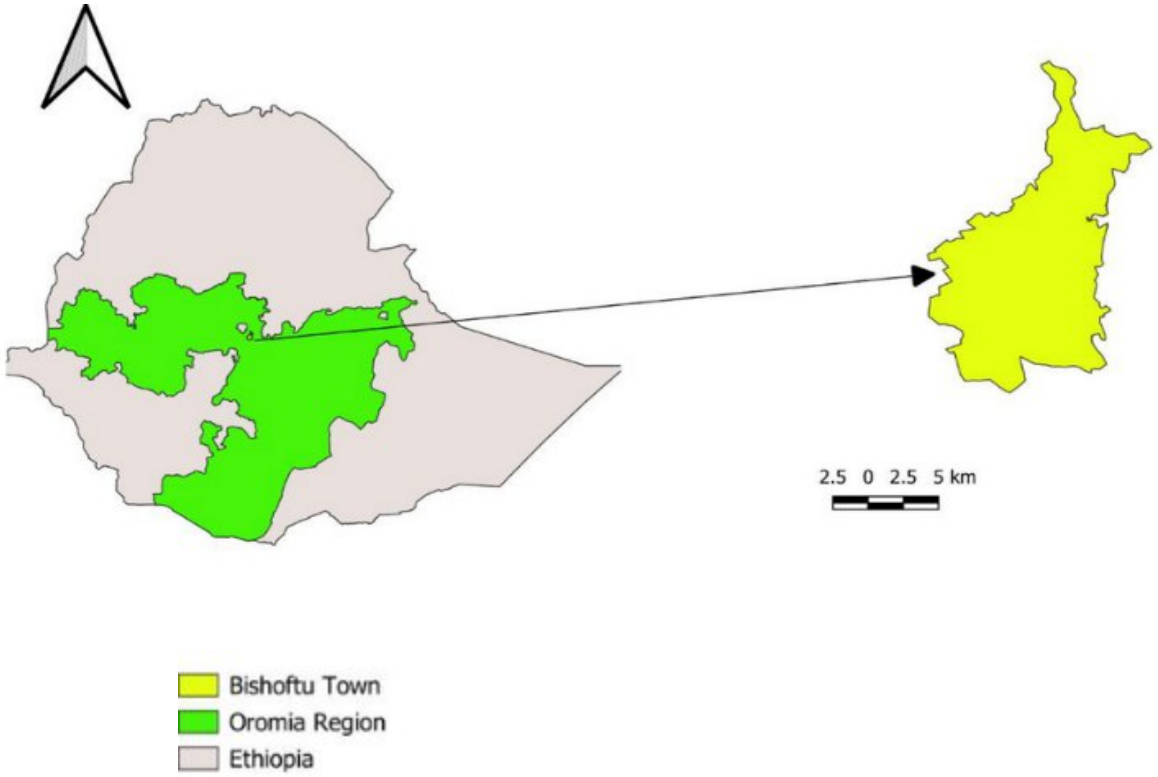



Figure 2: Map of experimental site

## 3.2. Description of Experimental-Materials

Lentil genotypes (Derso, Furi and Beredu varieties, which were released by Bishoftu

Agricultural Research Center in 2012, 2020 and 2019 and local cultivar (Table 2). These varieties are chosen based on their growth characteristics, yield potential, disease resistance for, and suitability to the environmental conditions of the region.

Table 2 Description of Experimental-Materials

| Variety Name | Year of Release | Breeder Source Center | Altitude Range (m.a.s.l.) | Annual Rainfall Range (mm) | Primary Target Agronomic Traits Remarks |
|---|---|---|---|---|---|
| Derso | 2012 | BARC | 1600 -2400 | 400 – 1200 | High yielding, early flowering, early maturing, and high biomass. |
| Beredu | 2019 | BARC | 700 – 1900 | 500 – 800 | Large seed size (high thousand-seed weight), high protein, preferred by local farmers. |
| Furi | 2020 | BARC | 1800 – 2400 | 700 – 1200 | High yielding, adapted to mid-to-high altitudes and sub-moist agro-ecologies, performs well on Vertisols. |
| Local Cultivar | — | Local Farmers (Study Area) | 1700 – 2400 | 700 – 1400 | Sourced locally from farmers; used as a check/control variety for adaptability and yield comparison. |

### 3.3. Soil Sampling and Analysis

A representative composite soil sample was taken using an auger from a surface layer of 0-20cm from eight spots in zigzag pattern of the entire experimental field and composited in to one sample unit before planting.

To prepare a representative composited soil sample and analyze it for key physicochemical properties, laboratories strictly follow standardized protocols

established by bodies like the Food and Agriculture Organization (FAO) and the International Soil Reference and Information Centre (ISRIC).

Field Collection] [ Air Drying] [ Crushing & Grinding] [ 2mm Sieving] [ Sub-sampling] (10-15 sub-samples) (Thin layer, ambient) (Break clods/aggregates) (Fine earth fraction) (Quartering method)

The composited soil sample was prepared following standard procedures and analyzed for Soil pH, Organic carbon, Organic matter, and Total Nitrogen, Available Phosphorus and Cation exchange capacity (CEC).

## 3.4. Treatment and Experimental Design

Four lentil genotypes (Derso, Furi, Beredu variety and Local cultivar), four phosphorus fertilizer rates (0, 23, 46 and 69 $P_2O_5$ kg $ha^{-1}$) were used in this study. The experiment was laid out in a Randomized Complete Block Design with (4*4) factorial arrangement with three replications.

## 3.5. Experimental Procedure and Field Management

The experimental field was prepared in the Adea District using standard, intensive agronomic practices suitable for Vertisols, involving meticulous primary and secondary tillage to create a fine, uniform seedbed. The layout was structured according to a randomized complete block design, incorporating clear, wide buffer zones between plots and robust drainage furrow installation to mitigate waterlogging, essential for optimal lentil production. For detailed guidance on your experimental methodology, consult academic resources on agricultural techniques. The plot was 2 * 3m ($6m^2$) and consisted of ten rows placed 20 cm apart. The distance between plants in a row was 2cm and thus about 150 plants per row and 1500 plants per plot were available. There was a distance of 50 cm between the plots and 1m between blocks. The total plots and blocks used for the study are 48 and 3, respectively.

The phosphorus fertilizer (TSP) was gained from Melkasa Agricultural Research Center and applied with seeds; 2 cm away about seeds were sown during mid- July a soil depth of 3 cm based on each treatment. After full emergence (10 days) of the seedling, the first weeding was carried out at twenty days after crop emergence.

The second weeding was carried out at forty-five days after crop emergence and the crop protection was practiced by applying Diazinon 60% EC insecticide chemical at 1.5-liter ha-1 two times; first at fifty-five days of emergence second at seventy days of emergence to control aphid.

## 3.6. Data Collection

Crop Phonological Parameters

Days to 50% emergence: - was determined by counting the number of days from sowing to the time when 50% emerged seeds.

Days to 50% flowering: - was determined as the number of days after seedling emergence to the period when 50% of the plants in a plot developed the first flower.

Days to 90% maturity: - was taken as the number of days after seedling emergence to the period when 90% of the plants in the plot were ready for harvesting based on visual observation. It was determined by the stage at which pods lost their pigmentation and began to dry and seeds hardened in the pod.

Crop Growth Parameters

Plant height (cm): - was measured by using a ruler at harvest maturity stage from the ground level to the tip of plant from randomly selected pre-tagged ten plants from six middle rows and expressed as an average of ten plants per plot.

Number of branches per plant: -ten select pre-tagged plants per plot from the middle six rows used to collect the data on both primary and secondary branches per plant. It was counted at the physiological maturity stage and averaged to give the number of branches per plant.

Nodulation Parameters

Total number of nodules: -was determined by counting the number of nodules from ten plants per plot and the mean value of the ten plants was recorded as the number of nodules per plant.

Effective number of nodules: -was measured by observing the color inside of nodules, which was observed by cutting with a sharp blade and a pink to dark-red color to be effective; whereas inactive nodules (non-effective nodules) were black, gray or greenish, white on the inside of nodules (Singh and Singh, 2016).

The number of effective nodules per plant was recorded by counting and were taking

the average per plant.

Nodule volumes: - were determined by displacement of water using a 5 ml graduate cylinder. First, a certain amount of water poured into the cylinder and their volumes were recorded.

The collected nodules were immersed in to the cylinder containing water.

The increment of water level after the nodules are immersed in the cylinder will considered as a volume of the nodules, which was measured in milliliter. The average nodules volume of ten plant samples has been taken as the nodule volume per plant.

Nodules fresh weight: was measured by using a sensitive balance to constant weight and expressed as the average nodules fresh weight of ten plant samples as nodules fresh weight per plant.

Nodules dry weight: was measured after drying the collected nodules in an oven at a temperature of 70 $^{0}_{c}$ for 48 hrs. Until constant weight is attained.

The averages of ten plants have been taken as a nodules dry weight per plant. It was reported as milligrams per plant.

## Yield and Yield Components

Yield attributes are determined at full maturity from randomly selected ten plants from six central rows. Crop stand count, number of pods per plant, number of seeds per pod, hundred seeds weight, above ground dry biomass per hectare, seed yield per hectare, straw yield per hectare and harvest index data were assessed at and after full maturity stage and threshing.

Number of pods per plant: - was recorded from ten randomly selected plants from the net plot area at harvest. The average result was reported as the number of pods per plant.

Number of seeds per pod: - was determined by the total number of seeds in ten randomly taken pods from the net plot, which was counted and divided by the total number of pods and expressed as average number of seeds per pod.

Thousand seed weight: - was sampled from each plot and weighed using a sensitive balance, the weight was adjusted at 10 % standard moisture content and expressed as grams per plot.

Dry biomass yield: - was recorded by weighing the total dry above-ground biomass harvested from each net experimental plot after sun drying for seven days and expressed in ton ha-1.

Grain yield: - was measured by harvesting the crop from the net plot area. The harvested lentil crop was sun-dried for seven days and threshed manually by putting the dried crop in a sack and hitting it with sticks. Then, winnowing was done using manual labor. The moisture content of the seed was adjusted to 10% then the weight was have converted to ton ha-1 as described by Biru, (1979).

Straw yield: -was measured as the difference between the total above-ground plant dry biomass and grain yield.

Harvest index: -was calculated by dividing grain yield per net plot area by total above- ground dry biomass yield per net plot area and multiplying by 100. The calculated Harvest index is expressed in percent.

## 3.7. Data Analysis

### 3.7.1. Statistical Analysis

The collected dates were analyzed using the General Linear Model (GLM) procedure (R Studio). Mean values are separated according to the standard procedure given by Gomez and Gomez (1984). Whenever the effects of the treatments are found to be significant, the means are compared using 5% level of Least Significant Difference (Steel et al., 1997).

### 3.7.2. Economic Analysis

The partial budget analysis was used following CIMMYT, (1988). The seed yield was adjusted 10% to reflect the real farm condition. The lentil grain and straw yield was valued at an average open market price of ETB 300 and ETB 1.5 $kg^{-1}$ respectively. Cost of land preparation, field management, harvest, transportation and storage were not included in the analysis, as they were not variable. The price of $P_2O_5$ fertilizer ETB 200 $kg^{-1}$ was used for economic analysis.

# 4. RESULTS AND DISCUSSION

## 4.1. Physicochemical Properties of the Soils before Sowing

The soil of the experimental site contained 34.4% clay, 38% silt and 27.6% sand (Table 2).

The textural class of the soil was a clay loam based on the classification of Benton (2012). Soil texture (proportion of sand, silt and clay) is an important physical property of soil as it determines water infiltration, soil water-holding capacity, ease of cultivation, aeration rate, and soil fertility (Gupta,2000). The soil reaction test indicates that the pH of the experimental site was 6.56. Thus, according to (Rayment, 2020) the soil reaction of the experimental site is slightly acidic, and the organic carbon content of the experimental site was 1.04%. Consequently, the organic carbon content of the site was moderate. Therefore, the recorded organic matter content (1.8 %) of the experimental soil was classified as medium. The soil of the study site has an average cation exchange capacity of (43.7 meq/100g) soil. The total nitrogen content of the experimental site of composite soil sample before planting was 0.1%. The available phosphorus level in the experimental site was 9.25pmm of soil. Similarly, Zelalam (2018) reported that the Cation exchange capacity of soil is an important parameter of soil because it gives an indication of the type of clay minerals present in the soil, its capacity to retain nutrients against leaching and assessing their fertility and environmental behavior and the chemical activity of the soil.

Therefore, the soil of the study area is nutrient deficient especially N and P to support crop production. This may be associated with poor farm management practices and continuous cropping with little or no fertilizers input which resulted in a decline in soil fertility of the area.

Table 3. physico chemical properties of the soils before sowing.

| Soil characters | Value | Rating | References |
|---|---|---|---|
| A. Physicochemical Analysis | | | |
| Sand (%) | 27.6 | - | Benton et al. (2012). |
| Silt (%) | 38 | - | Benton et al. (2012). |
| Clay (%) | 34.4 | - | Benton et al. (2012). |
| Textural class | - | Clay Loam | Benton et al. (2012). |
| Soil pH (1:2.5 H O) | 6.56 | Slightly acidic | Bruce and Rayment (1982) |
| Organic Carbon (%) | 1.38 | Moderate | Walkley and Black, ( 1934) |
| Organic Matter (%) | 4.11 | Medium | Roy et al. (2006) |
| CEC (cmol kg-1) | 22.3 | Medium | Rhoades (1977) |
| Electric Conductivity (d m/ s) | 0.18 | Medium | Rhoades, 1977 |
| Total N (%) | 0.16 | Low | Landon, (1991) |
| Available P (mm) | 9.25 | Low | |

## 4.2. Phenological Parameters

### 4.2.1. Days to 50% Emergence

The results showed that the interaction between $P_2O_5$ fertilizer rates and lentil varieties, as well as their separate effects, did not significantly ($P < 0.05$) affect the number of days required for seedling emergence (Table 3). The lack of response to the treatments is likely due to the favorable environmental conditions during planting, which were suitable for seed germination and early sprout growth. In all treatments, more than half of the seedlings emerged within seven days after sowing.

This suggests that fertilizer application and varietal differences had little influence at this early stage, since seeds mainly rely on their own stored food reserves during germination and initial emergence.

This observation agrees with the findings of Zelalem (2018), who reported that lentil seeds depend largely on internal nutrient reserves rather than external fertilizer during germination. Likewise, Tafes et al. (2020) noted that days to emergence showed very little variation among lentil varieties, indicating that this trait is not highly sensitive for distinguishing varieties. Hassain (2016) also found that the time required to reach 50% seedling emergence in lentil was not significantly affected by either varietal differences or fertilizer application rates.

Table 4. . Main effect of $P_2O_5$ fertilizer rates with Varieties on days to 50% emergence of lentil in Adea District

| Treatment | 50% Emergence |
|---|---|
| $P_2O_5$ | 50% of the date of emergence |
| 0 | 7.00 |
| 23 | 7.00 |
| 46 | 7.00 |
| 69 | 7.00 |
| LSD (5%) | NS |
| Varieties | |
| Local | 7.00 |
| Derso | 7.00 |
| Furi | 7.00 |
| Beredu | 7.00 |
| LSD | NS |
| CV | NS |

### 4.2.2. Days to 50% Flowering

The analysis of variance shows that the number of days required to reach 50% flowering had highly significant only on variety ($P < 0.001$), and the interaction had not significantly on 50% of flowering (Table 4).

The longest time to 50% flowering (65 days) was recorded when 69 kg P $ha^{-1}$ was applied to the Derso variety, while the shortest was (63 days) with local cultivar. These findings agreed with Merkine (2019), who reported that days to 50% flowering among lentil genotypes ranged from 52.7 to 78.3 days, with an average of 60.7 days. These findings agree with Merkine (2019), who reported that days to 50% flowering among lentil genotypes ranged from 52.7 to 78.3 days, with an average of 60.7 days.

### 4.2.3. Days to 90 % Physiological Maturity

The analysis of variance shows both $P_2O_5$ fertilizer rates ($P < 0.001$) and variety ($P < 0.001$) had a significant effect on the time required for lentil to reach 90% physiological maturity (Table 4). The improved variety, Derso, matured earlier, taking 97 days, while the local cultivar took the longest, 102 days. This difference is likely due to genetic variations among the lentil genotypes. Similar observations have been reported by Nigussie and Abiro (2019) and Alemayehu et al. (2014), who found notable differences among lentil genotypes in terms of flowering time, maturity, and grain-filling duration. According to Kumari et al. (2024) also showed that increasing phosphorus rates from 0 to 23, 46, and 69 kg $P_2O_5$ $ha^{-1}$ slightly but significantly shortened the time to maturity. These findings suggest that while phosphorus fertilization can help reduce the growing period to some extent, the genetic makeup of the variety remains the main factor determining crop maturity.

Table 5. The interaction effect of $P_2O_5$ fertilizer rates with varieties of 50% flowering and 90% physiological maturity of lentil in Adea District

| Varieties | $P_2O_5$(kg ha-1) | Days to 50% flowering | Days to 90% of physiological maturity |
|---|---|---|---|
| Local | 0 | 63[a] | 100.33[a] |
| | 23 | 63[a] | 100.33[a] |
| | 46 | 63[a] | 100.33[a] |
| | 69 | 63[a] | 100.36[b] |
| Derso | 0 | 65[c] | 98.00[c] |
| | 23 | 65[c] | 97.00[d] |
| | 46 | 65[c] | 97.00[d] |
| | 69 | 65[c] | 97.00[d] |
| Beredu | 0 | 64[b] | 98.00[c] |
| | 23 | 64[b] | 98.00[c] |
| | 46 | 63[c] | 97.00[d] |
| | 69 | 63[c] | 97.00[d] |
| Furi | 0 | 64[b] | 98.00[c] |
| | 23 | 64[b] | 98.00[c] |
| | 46 | 64[b] | 97.00[d] |
| | 69 | 64[b] | 97.00[d] |
| | LSD (%) | 0.25 | 1.08 |
| | CV (%) | 7.90 | 3.63 |

## 4.4. Growth Parameters

### 4.4.1. Plant height

These Analysis of variance showed that lentil plant height was significantly influenced by phosphorus fertilizer rates ($P < 0.001$), variety ($P < 0.01$), and the interaction between the two ($P < 0.001$) (Table 5). The tallest plants, reaching 43 cm, were observed in the improved variety Derso when fertilized with 69 kg P $ha^{-1}$, whereas the shortest plants, at 26 cm, occurred in the unfertilized control plots. The strong interaction between variety and phosphorus rate indicates that Derso has a higher genetic potential for vertical growth and responds more effectively to nutrient application than the local cultivar. This aligns with findings by Bekele et al. (2023) and Singh and Kumar (2024), who reported that adequate phosphorus boosts internode elongation and overall canopy height, especially in high-yielding, responsive legume varieties.

Overall, plant height increased with higher $P_2O_5$ application, but the response differed among varieties. For Derso, height increased steadily with increasing phosphorus, peaking at 43 cm with the highest rate. This suggests that while phosphorus supports cell division and elongation, genetic factors play a major role in how efficiently a plant uses the nutrient.

These results are consistent with Zafar et al. (2023), who observed that optimal phosphorus promotes stem elongation, but growth may plateau if either the variety's genetic potential or nutrient levels become limiting .Bottom of Form

### 4.4.2. Number of Primary Branches

The analysis of variance shows that the number of primary branches per plant was significantly influenced by both phosphorus fertilizer rates ($P < 0.01$) and variety ($P < 0.001$), with their interaction also showing a highly significant effect (Table 5).

The improved variety Derso produced the most primary branches (6.11) when supplied with 69 kg $ha^{-1}$ of $P_2O_5$, while the local variety produced only 3.65 branches under the unfertilized control. The strong response in Derso indicates that phosphorus supports the activation of axillary buds by improving the plant's internal nutrient supply.

These findings align with Mekonnen and Tadesse (2022), who reported that phosphorus deficiency limits axillary bud development, whereas adequate phosphorus boosts photosynthetic efficiency and encourages the formation of effective primary branches. Similarly, Hossain (2016) observed clear differences in branching among lentil varieties. Singh and Singh (2016) and Merkebu (2019) also noted that branch development is closely tied to nutrient availability, with higher nutrient levels promoting more extensive branching.

### 4.4.3. Number of Secondary Branches

The number of secondary branches per plant was significantly affected by phosphorus fertilizer rate, variety, and their interaction ($P < 0.01$) (Table 5). The interaction revealed a strong positive response, with the highest numbers of secondary branches observed at elevated phosphorus levels.

The improved variety Derso produced the highest number of secondary branches (9.22) at 69 kg $P_2O_5$ $ha^{-1}$, significantly exceeding the Local variety, which ranged from 3.95 to 5.32 branches across the phosphorus treatments. This result indicates that Derso is a superior genotype with greater responsiveness to nutrient availability. Its strong branching performance under higher phosphorus supply suggests enhanced physiological sensitivity to improved nutrient conditions.

Alemu et al. (2023) emphasized the importance of optimized phosphorus nutrition for maximizing the development of the secondary vegetative framework. The present findings align with this observation, as secondary branching showed a similar trend and served as a key indicator of yield potential. According to Wondimu (2024) and Brady (2023) reported that higher phosphorus levels improve the source-sink balance, allowing plants to support a larger vegetative structure and more reproductive sites. Similarly, Dhillon et al. (2023) identified secondary branching as a key yield-contributing trait that reaches its full potential only when phosphorus supply satisfies the metabolic demands of the cultivar.

Table 6. The interaction effect of $P_2O_5$ fertilizer rates with Varieties on plant height, number of primary branch and secondary branch of lentil in Adea District

| Varieties | $P_2O_5$ (kg ha-1) | Plant height(cm) | Number of primary branches | Number of secondary Branches |
|---|---|---|---|---|
| Local | 0 | 26.00$^{k}$ | 3.65$^{i}$ | 5.31$^{k}$ |
| | 23 | 26.00$^{k}$ | 3.65$^{i}$ | 5.31$^{k}$ |
| | 46 | 32.65$^{j}$ | 3.55$^{j}$ | 5.31$^{k}$ |
| | 69 | 32.00$^{j}$ | 3.65$^{i}$ | 5.32$^{j}$ |
| Derso | 0 | 40.12$^{c}$ | 5.53$^{c}$ | 7.17$^{e}$ |
| | 23 | 37.11$^{f}$ | 5.41$^{e}$ | 7.14$^{f}$ |
| | 46 | 41.00$^{b}$ | 5.82$^{b}$ | 8.11$^{c}$ |
| | 69 | 43.00$^{a}$ | 6.11$^{a}$ | 9.22$^{a}$ |
| Beredu | 0 | 38.11$^{e}$ | 4.75f | 7.11$^{g}$ |
| | 23 | 40.00$^{d}$ | 5.43$^{d}$ | 7.14$^{f}$ |
| | 46 | 34.00$^{i}$ | 3.85$^{h}$ | 5.56$^{i}$ |
| | 69 | 35.00$^{h}$ | 4.45$^{g}$ | 6.11$^{h}$ |
| Furi | 0 | 38.11$^{e}$ | 5.43$^{d}$ | 7.11$^{g}$ |
| | 23 | 40.00$^{d}$ | 5.43$^{d}$ | 7.14$^{f}$ |
| | 46 | 36.00$^{g}$ | 5.43$^{d}$ | 8.12$^{b}$ |
| | 69 | 36.00$^{g}$ | 5.43$^{d}$ | 7.11$^{g}$ |
| | LSD (%) | 0.16 | 0.88 | 0.22 |

| | | | |
|---|---|---|---|
| CV (%) | 3.40 | 3.41 | 4.40 |

## 4.5. Nodulation Parameters

### 4.5.1. Total Number of Nodules per Plant

The analysis of variance showed that the main effects of phosphorus fertilizer rates and varieties significantly influenced the total number of nodules per plant ($P < 0.001$) and the interaction between phosphorus level and variety also showed a significant effect phosphorus rates on the Number of Nodules was highly significant,

revealing distinct genetic differences in response to soil fertility. (Table 6).

In general, increasing $P_2O_5$ from 0 to 69 kg $ha^{-1}$ led to a rise in nodule numbers across all varieties, with the highest values observed at 69 kg $ha^{-1}$, particularly in the Derso variety (17.33). In contrast, the local variety showed only a slight increase (9.66–10.00), indicating a limited response to phosphorus application. However, the extent of this response varied among genotypes, confirming that nodulation is strongly influenced by genetic factors.

Similar results have been reported by Amoako et al. (2023), who found that phosphorus application increased nodule numbers in responsive legume genotypes by improving root growth and energy supply for symbiosis.

The strong response observed in the Derso variety may be explained by the role of phosphorus in root proliferation. Studies conducted in the Ethiopian highlands by Tadesse et al. (2023) and Bekele (2024) also indicate that phosphorus application in responsive varieties enhances the release of root exudates, such as flavonoids, which attract rhizobia and promote greater nodule formation compared with unfertilized local varieties.

According to Tolera et al. (2024), adequate phosphorus application in Ethiopian soils enhances root architecture and increases the sites available for rhizobial infection, thereby significantly boosting nodule initiation in improved varieties compared to local landraces.

### 4.5.2. Number of Effective Nodules per Plant

The analysis of variance shows that the effect of $P_2O_5$ fertilizer ($P<0.001$) and varieties ($P<0.001$) significantly affected the number of effective nodules per plant. Moreover, the interaction of P fertilizer rates with varieties significantly ($P<0.001$) affected nodules effectiveness (Table 6). The maximum number of effective nodules per plant (16.50) was recorded with application of 69 kg $P_2O_5$ ha-1 fertilizer with Varieties, while the minimum number of the effective nodules per plant (9) was recorded from control. Merkebu (2019) reported that varieties and the application of chemical fertilizers showed significant effect on the number of effective nodules plant-1. The color of leghemoglobin in actively fixing nitrogen nodules is pink to beef-red which is due to an iron-containing pigment, while non-N2-fixing nodules have a

white or green color (Singh and Singh, 2016). Recent research highlights that effective nodulation depends not only on nodule number but also on nutrient availability, especially phosphorus, which drives nitrogenase activity and energy metabolism (Teshome et al., 2024).

Thus, the results suggest that Derso has superior symbiotic efficiency, while other varieties may require additional factors (e.g., inoculation or micronutrients) to improve effectiveness.

The increase in effective nodules with higher phosphorus rates is crucial because phosphorus is the primary energy source (ATP) required for the nitrogenase enzyme to fix atmospheric nitrogen.

The data revealed a highly significant difference in the number of effective nodules (those actively fixing nitrogen) due to the treatment combinations. The superior performance of the Derso variety indicates a high physiological efficiency in maintaining the symbiosis with nitrogen-fixing bacteria.

This finding is supported by Gemechu and Eshetu (2023), who reported that phosphorus deficiency limits the synthesis of leghaemoglobin (the pigment responsible for effectiveness), and that increasing $P_2O_5$ supply ensures that formed nodules remain active and functional for nitrogen fixation.

### 4.5.3. Volume of Nodules per Plant

The main effect of $P_2O_5$ fertilizer on varieties significantly ($P<0.001$) affected nodule volume per plant. Moreover, the interaction of P fertilizer rates with varieties significantly ($P<0.001$) affected the volume of nodules per plant of lentil, while other interactions had highly a significant effect on the volume of nodules per plant (Table 6). Nodule volume (or weight) also increased with phosphorus application, though the changes were relatively small compared to nodule number.

The largest nodule volume (0.19) was recorded in the Derso variety at 69 kg $P_2O_5$, whereas the smallest value (0.13) occurred in the local variety under lower phosphorus levels.

Larger nodules generally indicate improved development and greater metabolic activity, which are closely linked to enhanced nitrogen fixation.

Phosphorus plays an important role in promoting cell division and expansion within

nodules, resulting in increased size and biomass.

Tilahun et al. (2023) also reported that adequate phosphorus supply improves both nodule size and leghaemoglobin content, which are essential for efficient nitrogen fixation.

Volume per plant of lentil, the interaction between crop variety and phosphorus fertilizer rates showed a highly significant effect on the Volume of Nodules. This biological response is supported by Demise and Tana (2024), who explain that phosphorus is the primary energy source (ATP) for symbiotic nitrogen fixation; increased $P_2O_5$ availability significantly enhances the translocation of photosynthesis (sugars) from the leaves to the root nodules, resulting in greater nodule volume and dry matter weight, which acts as a sink for nitrogen assimilation.

Table 7. The Main interaction effect of $P_2O_5$ fertilizer rates with Varieties on the Number of Nodules per plant, Number of Effective the number of nodules per plant and nodules Volume of weight of Lentil per plant in Adea District

| Varieties | $P_2O_5$ (kg ha-1) | Number of nodules | Number of effective nodules | nodules Volume of weight |
|---|---|---|---|---|
| | 0 | 9.66$^{k}$ | 8.17$^{i}$ | 0.14$^{h}$ |
| | 23 | 9.67$^{j}$ | 9.00$^{h}$ | 0.14$^{h}$ |
| Local | 46 | 9.67$^{j}$ | 9.00$^{h}$ | 0.13$^{j}$ |
| | 69 | 10.00$^{i}$ | 9.00$^{h}$ | 0.15$^{f}$ |
| | 0 | 13.11$^{d}$ | 11.00$^{d}$ | 0.14$^{i}$ |
| | 23 | 15.16$^{c}$ | 13.43$^{c}$ | 0.16$^{d}$ |
| Derso | 46 | 15.17$^{b}$ | 15.10$^{b}$ | 0.17$^{c}$ |
| | 69 | 17.33$^{a}$ | 16.50$^{a}$ | 0.19$^{b}$ |
| | 0 | 11.00$^{h}$ | 10.00$^{f}$ | 0.15$^{b}$ |
| | 23 | 12.00$^{f}$ | 10.00$^{f}$ | 0.15$^{b}$ |
| Beredu | 46 | 11.00$^{h}$ | 10.12$^{e}$ | 0.16$^{a}$ |
| | 69 | 12.00$^{f}$ | 10.12$^{e}$ | 0.16$^{a}$ |
| | 0 | 11.12$^{g}$ | 10.00$^{f}$ | 0.14$^{g}$ |
| | 23 | 12.00$^{f}$ | 10.00$^{f}$ | 0.16$^{e}$ |
| Furi | 46 | 11.00$^{h}$ | 10.12$^{e}$ | 0.14$^{i}$ |
| | 69 | 13.00$^{e}$ | 10.12$^{e}$ | 0.16$^{e}$ |
| | LSD (%) | 1.17 | 1.12 | 1.00 |
| | CV (%) | 3.20 | 3.46 | 1.37 |

Values with the different letter(s) in a column are significantly different at 5%probability level.

### 4.5.4. Nodules Fresh Weight

The weight and size of nodule depends on specific activity of Rhizobia. The analysis of variance shows the main effects of $P_2O_5$ fertilizer rates and varieties highly significant on ($P<0.001$) affected nodule fresh weight. Similarly, the interaction of $P_2O_5$ fertilizer rates with varieties highly significantly ($P<0.001$ and $P<0.01$) affected nodule fresh weight respectively; (Table 6)

The most efficient bacterium stimulates the formation of nodule, which provides legumes with nitrogen, so the plants can develop a greater weight of nodule (Laila et al., 2015). The Nodule Fresh Weight was significantly influenced by the interaction between varieties and phosphorus application rates. Among the genotypes, variety Derso exhibited the highest physiological responsiveness to phosphorus nutrition. As the phosphorus rate increased from 0 to 69 kg $P_2O_5$ $ha^{-1}$, performance improved markedly. This response can be attributed to the variety's genetic efficiency in using phosphorus to stimulate root growth and nodule initiation.

Similar results were reported by Masa et al. (2022) and Tesfaye and Balcha (2023), who found that adequate phosphorus availability in Ethiopian soils increases nodule volume and weight by supplying the ATP required for rhizobial activity. However, the decline observed at higher rates suggests that some varieties may have a relatively low critical phosphorus threshold. Beyond this level, excessive phosphorus can disrupt nutrient balance and suppress nodule development, a phenomenon previously described in legume physiology by Beebe et al. (2021).

### 4.5.5. Nodules Dry Weight

The analysis of variance showed that the two-way interaction effects of P fertilizer rates and varieties were significantly ($P<0.001$) affected by nodules dry weight per plant of lentil (Table 8). The higher nodule dry weight (15 mg) was recorded by

application of 69 kg P ha-1 fertilizer on the Derso variety, while the lowest nodule dry weight per plant (7 mg) was recorded from 0 kg P ha-1 on the local cultivar. Application of 69 kg P ha-1 fertilizer on the Derso variety increased the nodule dry weight per plant by 53.97% over the control fertilizer with local variety. Zelalam (2018) also reported great variation was observed in the Derso variety followed by local varieties on nodule number and nodule dry weight.

Table 8. The Main interaction effect of P2O5 fertilizer rates with Varieties on the number of nodules fresh weight and nodules dry weight of lentil in Adea District

| Varieties | $P_2O_5$ (kg ha-1) | Nodule fresh weight | Nodule dry weight |
|---|---|---|---|
| Local | 0 | 37.23$^{jk}$ | 12.00$^{i}$ |
| | 23 | 37.23$^{k}$ | 12.00$^{i}$ |
| | 46 | 38.21$^{j}$ | 11.20$^{j}$ |
| | 69 | 39.00$^{i}$ | 13.00$^{g}$ |
| Derso | 0 | 45.00$^{d}$ | 12.30$^{d}$ |
| | 23 | 46.00$^{c}$ | 13.30$^{c}$ |
| | 46 | 51.08$^{b}$ | 14.14$^{b}$ |
| | 69 | 56.15$^{a}$ | 17.73$^{a}$ |
| Beredu | 0 | 42.22$^{g}$ | 13.02$^{f}$ |
| | 23 | 39.00$^{i}$ | 13.13$^{d}$ |
| | 46 | 39.00$^{i}$ | 11.00$^{k}$ |
| | 69 | 40.00$^{h}$ | 11.00$^{k}$ |
| Furi | 0 | 42.22$^{g}$ | 13.02$^{f}$ |
| | 23 | 43.11$^{f}$ | 13.12$^{e}$ |
| | 46 | 39.00$^{i}$ | 11.00$^{k}$ |
| | 69 | 40.00$^{h}$ | 10.00$^{l}$ |
| LSD | | 0.11 | 0.65 |
| CV (%) | | 7.09 | 4.33 |

## 4.6. Yield and Yield Component Parameters

### 4.6.1. Number of Pods per Plant

The number of pods per plant is the most influential yield component and it is the most closely correlated with seed yield. The main effects of P fertilizer rates and varieties, ($P<0.001$) and their two-way interaction significantly ($P<0.01$) highly significant effected number of pods per plant (Table 8).

The highest number of pods per plant (65) was recorded from application of blended 69 kg Pha-1 fertilizer with Derso variety; while the lowest number of pods per plant 48 was recorded from control on local cultivar. Application of 69 kg P ha-1 fertilizer with the Derso variety increased number of pods per plant by 61.85% over the control fertilizer treatment on the local cultivar.

This significant variation is attributed to the role of phosphorus in flower formation and retention; adequate P minimizes flower abortion and enhances the transition from flowering to pod setting. This result agreed with Tesfahun (2007); Hossain (2016) who reported that number of pods per plant was significantly affected by varieties and nutrients interaction. Likewise, Merkebu (2019) reported that the interaction of different fertilizer rates with the significantly affected the number of pods per plant of Mung bean.

### 4.6.2. Number of Seeds per Pod

The number of seeds per pod was significantly affected by the main effect of P fertilizer rates ($P<0.05$) and varieties ($P<0.01$) and the two-way interaction of P fertilizer with varieties ($P<0.01$). (Table 8).

NSPP is a trait governed heavily by genetic potential once a minimum phosphorus threshold is met. As argued by Raza et al. (2023), phosphorus plays a critical role in

energy transfer (ATP) during seed formation; however, the physical capacity of the pod to hold seeds often acts as a biological ceiling that nutrient application cannot exceed.

The lowest seeds per pod (1 Seed pod-1) were recorded from blended 0 kg P ha-1 fertilizer with local cultivar of lentil while all other treatment combination gave statistically at par seed per pod. This indicated that improved variety has the capacity to hold higher seeds per pod than the local cultivar even low rate of application of P fertilizer. Similarly, Merkine (2019) reported that lentil varieties differed for number of seeds produced pod-1.

The number of seeds per pod was increased by increasing the rate of P fertilizer per hectare in both varieties. Likewise, Tesfahun (2007); Jihad (2016) and Guriqbal et al. (2011) reported that number of seeds per pod was significantly different among the interaction of varieties and phosphorus rates.

Arega and Zenebe (2019) also reported numbers of seeds per pod was significantly ($P<0.05$) affected due to varieties in common bean.

Table 9. The Main effect of $P_2O_5$ fertilizer rates with Varieties on number of pods per plant and number of seeds per pod of lentil in Adea District

| Varieties | $P_2O_5$(kg ha$^{-1}$) | NPP | NSPP |
|---|---|---|---|
| Local | 0 | 36.00$^{j}$ | 1.33$^{g}$ |
| | 23 | 36.00$^{j}$ | 1.33$^{g}$ |
| | 46 | 36.00$^{j}$ | 1.34$^{f}$ |
| | 69 | 38.00$^{i}$ | 1.44$^{e}$ |
| Derso | 0 | 52.00$^{de}$ | 2.00$^{a}$ |
| | 23 | 65.00$^{a}$ | 2.00$^{a}$ |
| | 46 | 58.80$^{c}$ | 2.00$^{a}$ |
| | 69 | 60.33$^{b}$ | 2.00$^{a}$ |
| Beredu | 0 | 46.00$^{h}$ | 1.93$^{d}$ |
| | 23 | 48.00$^{g}$ | 1.97$^{c}$ |
| | 46 | 50.00$^{f}$ | 2.00$^{a}$ |

| | | | |
|---|---|---|---|
| | 69 | 53.00[d] | 2.00[a] |
| | 0 | 46.00[h] | 1.93[d] |
| | 23 | 48.00[g] | 1.98[b] |
| Furi | 46 | 50.00[f] | 2.00[a] |
| | 69 | 51.00[ef] | 2.00[a] |
| | LSD (%) | 1.47 | 1.01 |
| | CV (%) | 1.00 | 1.83 |

Values with the different letter(s) in a column are significantly different at 5% probability level.

### 4.6.3. Thousand Seed Weight

Seed weight is an important quality attribute of crops. Although this character is

genetically controlled, the growing condition also exerts considerable influence on its Expression (Moshiul et al., 2018). The main effect of P fertilizer rates and varieties ($P<0.001$) and the interaction of P fertilizer rates with varieties significantly ($P<0.01$) affect thousand seed weight. Similarly, other interaction had highly significant effect the thousand-seed weight of lentil (Table 10).

The highest thousand-seed weights (28g) were obtained by application of 46 and 69 kg P ha-1 fertilizer on Derso variety, respectively (Table 10). While the lowest thousand-seed weight, (23 g) was recorded from control with local cultivar. Application of 46 and 69 kg P ha-1 fertilizer with Derso variety produced 28 and 23.83% higher thousand-seed weight over the control fertilizer treatment with local cultivar. Similarly, Zelalam (2018) reported that the variability of thousand-seed weight was due to the interaction effect of varieties and $P_2O_5$ rates. Tesfahun (2007); Singh et al. (2011) also reported the interaction effect of varieties and rates of phosphorus significantly affects the thousand seed weight. Lentil thousand seeds weight ranged from 19.0 to 44.5 g (Merkine, 2019). This suggests a genotype-specific physiological limit to seed size.

These results are corroborated by Hussain et al. (2023), who stated that while phosphorus application enhances the starch synthesis enzymes in developing seeds, the final seed weight is often constrained by the genetic "sink capacity" of the variety once optimal phosphorus requirements are met. This dual advantage is a hallmark of superior nutrient-responsive cultivars, as highlighted by Wang et al. (2024) regarding phosphorus-efficient crop breeding. Physiologically, the increase in TSW with increasing phosphorus levels particularly in the responsive Derso variety (increasing from 27.00 g to 28.68 g) is attributed to the role of phosphorus in energy transfer (ATP) and starch synthesis during the grain-filling period.

Table 10. The main interaction effect of $P_2O_5$ fertilizer rates with varieties on thousand weight of lentil in Adea District

| Varieties | $P_2O_5$(kg ha-1) | Thousand seed weight |
|---|---|---|
| Local | 0 | 21.83[i] |
| | 23 | 21.83[i] |
| | 46 | 23.83[h] |
| | 69 | 24.00[g] |
| Derso | 0 | 27.00[d] |
| | 23 | 27.43[c] |
| | 46 | 28.67[b] |
| | 69 | 28.68[a] |
| Beredu | 0 | 25.00f |
| | 23 | 25.00[f] |
| | 46 | 26.00[e] |
| | 69 | 25.00f |
| Furi | 0 | 25.00[f] |
| | 23 | 25.00[f] |
| | 46 | 26.00[e] |
| | 69 | 26.00[e] |
| | LSD (%) | 2.42 |
| | CV (%) | 3.14 |

Values with the different letter(s) in a column are significantly different at 5% probability level

### 4.6.4. Dry Biomass Yield

The main interaction effect of $P_2O_5$ fertilizer rates ($P<0.001$) and varieties ($P<0.001$) or the two-way interaction of the main factors significantly ($P<0.05$) affected dry biomass yield of lentil (Table 10).

The highest biomass (4.86 t ha$^{-1}$) was recorded from Derso variety at 69 kg $P_2O_5$ ha$^{-1}$, followed by Derso at 46 kg $P_2O_5$ ha$^{-1}$ (4.64 t ha$^{-1}$). In contrast, the lowest biomass (1.88 t ha$^{-1}$) was obtained from unfertilized local cultivar. This result agreed with Zelalem, (2018) who reported that the highest (4.7 t ha-1) dry biomass was recorded with the application of 69 kg P ha-1.

Application of 69 kg P ha-1 fertilizer rates with Derso variety produced higher dry biomass, which is 52.57% over the control on local cultivar.

. The results showed a clear and consistent increase in dry biomass yield as the rate of $P_2O_5$ application increased across all lentil varieties.

The highest biomass yield was recorded in the Derso variety at 69 kg $P_2O_5$ ha$^{-1}$, while the lowest biomass was observed in the unfertilized local cultivar. This pattern indicates that phosphorus plays a crucial role in stimulating vegetative growth and enhancing overall dry matter production in lentil.

These observations agree with recent research, which has shown that lentil responds strongly to phosphorus fertilization because many soils are naturally low in available phosphorus and the crop has a high demand for this nutrient during early growth stages.

For example, a 2024 field experiment found that phosphorus application significantly increased plant height, dry weight, crop growth rate, and total biomass in lentil, highlighting the importance of phosphorus for early growth and biomass accumulation (Agronomy Journal, 2024).

Another study also reported that higher phosphorus levels improved plant dry weight and overall growth by promoting better root development and more efficient nutrient uptake (Biochemistry Journal, 2024)

### 4.6.5. Grain Yield

The analysis of variance revealed that both the main effect of $P_2O_5$ fertilizer rates, varieties and the interaction between fertilizer rates and lentil varieties were highly significant

($P < 0.001$) (Table 10). Among the treatments, the Derso variety achieved the highest grain yield of 2.29 t $ha^{-1}$ at 69 kg $P_2O_5$ $ha^{-1}$, whereas the lowest yield of 1.0 t $ha^{-1}$ was recorded in the unfertilized local cultivar.

This substantial yield gap highlights the combined influence of genotype and phosphorus availability on lentil productivity.

These results are consistent with Zewide et al. (2021) reported that mineral phosphorus application significantly improves yield components such as fertile tillers and grain number, which helps explain the higher performance of improved varieties compared to local genotypes.

Melese et al. (2025) also demonstrated that improved lentil varieties in the Ethiopian highlands respond strongly to phosphorus fertilization, further emphasizing the importance of combining high-yielding genotypes with adequate nutrient supply for maximum productivity.

### 4.6.6. Straw Yield

The analysis of results showed that the main factors of Phosphorus fertilizer rates ($P<0.001$) and varieties ($P<0.001$), and the interaction of P fertilizer with varieties ($P<0.001$) (Table 10). Among the treatments the highest straw yield (2.9 t ha-1) was recorded on Derso variety with the application of 46 kg P ha-1 fertilizer, while the lowest straw yield (1.67 t ha-1) was obtained from Phosphorus un-fertilized local cultivar.

These findings are supported by recent research demonstrating that phosphorus fertilization can substantially increase haulm or stover yield in lentil by promoting overall vegetative development.

Similarly, Singh et al. (2023) reported significant increases in straw production of lentil with phosphorus fertilization.

The increase in straw yield with phosphorus can be attributed to enhanced photosynthetic capacity and structural development.

Table 11. The interaction effect of $P_2O_5$ fertilizer rates with varieties on Dry biomass yield, Grain yield and Straw weight of lentil in Adea District

| Varieties | $P_2O_5$ (kg ha-1) | DBY (t ha$^{1}$) | GY (t ha$^{-1}$) | STRYW (t ha -1) |
|---|---|---|---|---|
| Local | 0 | 1.88$^{g}$ | 0.66$^{h}$ | 1.28$^{e}$ |
| | 23 | 2.09$^{g}$ | 0.70$^{h}$ | 1.41$^{e}$ |
| | 46 | 2.48$^{f}$ | 0.92$^{g}$ | 1.45d$^{e}$ |
| | 69 | 2.62$^{f}$ | 0.99$^{g}$ | 1.74$^{d}$ |
| Derso | 0 | 3.52$^{e}$ | 1.40$^{f}$ | 2.17$^{c}$ |
| | 23 | 3.68c$^{de}$ | 1.54$^{de}$ | 2.16$^{c}$ |
| | 46 | 4.64$^{a}$ | 2.01$^{b}$ | 2.76$^{a}$ |
| | 69 | 4.86$^{a}$ | 2.29$^{a}$ | 2.54$^{ab}$ |
| Beredu | 0 | 3.60$^{e}$ | 1.40$^{f}$ | 2.20$^{c}$ |
| | 23 | 3.65$^{de}$ | 1.42$^{ef}$ | 2.23$^{bc}$ |
| | 46 | 3.85$^{bcd}$ | 1.66$^{cd}$ | 2.19$^{c}$ |
| | 69 | 3.88$^{bc}$ | 1.67$^{c}$ | 2.20$^{c}$ |
| Furi | 0 | 3.61$^{e}$ | 1.40$^{f}$ | 2.21$^{c}$ |
| | 23 | 3.67$^{cde}$ | 1.42$^{ef}$ | 2.25$^{bc}$ |
| | 46 | 3.84$^{bcd}$ | 1.65$^{cd}$ | 2.19$^{c}$ |
| | 69 | 3.93$^{b}$ | 1.68$^{c}$ | 2.26$^{bc}$ |
| | LSD | 0.22 | 0.22 | 0.32 |
| | CV (%) | 2.08 | 3.11 | 5.1 |

### 4.6.7. Harvest Index

The results of the analysis of variance clearly showed that $P_2O_5$ fertilizer rates, lentil varieties, and their interaction had a highly significant effect ($P < 0.001$) on the harvest index of lentil (Table 11). The Derso variety produced the highest harvest index (42.67%) when supplied with 69 kg $P_2O_5$ $ha^{-1}$, while the lowest value was obtained from the unfertilized local cultivar. According to Fageria et al. (2022) explained that adequate phosphorus improves the partitioning of dry matter, which in turn increases the harvest index in grain legumes.

In the same way, Kumar et al. (2023) reported that phosphorus fertilization enhances lentil harvest index by encouraging better pod formation and seed development. Differences among lentil varieties have also been highlighted by Ali et al. (2024) and Melese et al. (2025), who found that improved varieties tend to achieve a higher harvest index because of their better genetic yield potential and stronger response to fertilizer. Moreover, Singh and Singh (2016) emphasized that balanced plant nutrition plays an important role in improving the harvest index.

Table 12. The Main effect of $P_2O_5$ fertilizer rates with Varieties on harvest index of lentil in Adea District

| Treatment | Parameter |
|---|---|
| $P_2O_5$(kg ha-1) | Harvest Index |
| 0 | 38.15b |
| 23 | 38.19[b] |
| 46 | 41.68[a] |
| 69 | 42.67[a] |
| Varieties | |
| Local | 35.90[c] |
| Derso | 43.00[a] |
| Furi | 40.81[b] |
| Beredu | 40.98[b] |

| | |
|---|---|
| LSD% | 0.16 |
| CV% | 3.6 |

Table 13 . Partial Budget analysis of (P2O5) Fertilizers rate and varieties on Lentil production in Adea district

| Variety | Treatment {kg\h) | Grain Yield | Adjusted Yield (kgha-1) | Gross Benefit | Total Variable Cost | Net Benefit(EBha-1) | Marginal Rate of Return (%) |
|---|---|---|---|---|---|---|---|
| Local | 0 | 1703 | 1532.7 | 459,810 | 700 | 459,110 | — |
| | 23 | 1671 | 1503.9 | 451,170 | 850 | 450,320 | D |
| | 46 | 1710 | 1539.0 | 461,700 | 1050 | 460,650 | D |
| | 69 | 1972 | 1774.8 | 532,440 | 1200 | 531,240 | D |
| Dersо | 0 | 4017 | 3615.3 | 1,084,590 | 850 | 1,083,740 | 237,500.00 |
| | 23 | 4120 | 3708.0 | 1,112,400 | 980 | 1,111,420 | 21,292.31 |
| | 46 | 4526 | 4073.4 | 1,222,020 | 1160 | 1,220,860 | 60,800.00 |
| | 69 | 4590 | 4131.0 | 1,239,300 | 1280 | 1,238,020 | 14,300.00 |
| Beredu | 23 | 3315 | 2983.5 | 895,050 | 860 | 894,190 | D |
| | 46 | 3475 | 3127.5 | 938,250 | 1000 | 937,250 | D |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 69 | 3479 | 3131.1 | 939,330 | 1150 | 938,180 | D |
| Furi | 0 | 3278 | 2950.2 | 885,060 | 780 | 884,280 | D |
| | 23 | 3321 | 2988.9 | 896,670 | 865 | 895,805 | D |
| | 46 | 3492 | 3142.8 | 942,840 | 960 | 941,880 | D |
| | 69 | 3498 | 3148.2 | 944,460 | 1140 | 943,320 | D |

# 5.CONCLUSIONS AND RECOMMENDATIONS

## 5.1. Conclusions

The results of this study confirmed that lentil productivity in the study area is strongly influenced by phosphorus fertilizer application and varietal selection.
The pre-sowing soil analysis indicated poor soil fertility, emphasizing the need for appropriate nutrient management to improve crop production. The results revealed that phosphorus fertilizer significantly improved growth, nodulation, yield components and grain yield of lentil.
The interaction between phosphorus rate and variety was highly significant, indicating that lentil varieties respond differently to phosphorus fertilization.
The highest grain yield, biomass yield, nodulation parameters and harvest index were obtained from the application of 69 kg $P_2O_5$ $ha^{-1}$ with the Derso variety.

Economic analysis also confirmed that this treatment produced the highest net benefit and acceptable marginal rate of return, making it the most economically viable option for farmers. Although yield increased with fertilizer rate for all varieties, the economically optimal phosphorus level differed among varieties. Higher fertilizer rates were not economically justified for Beredu and Furi varieties due to lower marginal returns.

Overall, the results highlight that lentil productivity in the study area is strongly constrained by phosphorus deficiency and the continued cultivation of low-yielding local varieties.

## 5.2. Recommendations

The use of 69 kg $P_2O_5$ $ha^{-1}$ combined with the Derso variety is recommended for farmers in Adea District and similar agro-ecologies to achieve higher lentil yield and profitability.

Development and dissemination of site-specific agronomic practices are essential for sustainable lentil production among smallholder farmers. Since the experiment was conducted at a single location and season, further multi-location and multi-season studies are recommended to validate the findings.

For farmers, the adoption of improved lentil varieties with appropriate phosphorus fertilization should be encouraged. For extension workers, training farmers on proper fertilizer application and improved production practices is essential.

Based on the findings of this research the following recommendations are made to improve lentil production and productivity in the study area.

Generally, to be more successful in lentil production it is important to develop and disseminate crop and site-specific agronomic practices for sustainable crop management practices among smallholder of the farmers in the study area.

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# 7. APPENDICES

Appendix 1. mean square of Anova Phenological parameters of lentil

| Source of variation | DF | Mean squares | | |
|---|---|---|---|---|
| | | 50 % DE | 50% DF | 90%DM |
| Block | 2 | 0 | 0 | 0 |
| Var | 1 | 0 | 48*** | 106.8*** |
| $P_2O_5$ | 3 | 0 | 0 | 0.04 |
| Var*$P_2O_5$ | 7 | 0 | 0 | 0.060 |
| Error | 30 | 0 | 0 | 0.055 |
| LSD (5%) | 0 | | 4.59 | 0.26 |
| CV (%) | - | | 6.38 | 0.23 |

Where: - *, **, ***: Significant at 0.05, 0.01 and .001 respectively, Var: Varieties, Var*$P_2O_5$: Interaction of Varieties with P2O5, Two-ways interaction of varieties with P2O5, DF: Degree of freedom: Days of 50% emergence, DF: Days to 50% flowering DPhM: Days to 90% physiological maturity.

Appendix 2.Mean square of Anova for growth parameters of lentil.

| Source of variation | | Mean squares | | |
|---|---|---|---|---|
| | DF | PH | NPB | NSB |
| Block | 2 | 0.00 | 0.00 | 0.06 |
| Var | 1 | 198.29*** | 9.86*** | 9.86*** |
| $P_2O_5$ | 3 | 20.69*** | 0.32*** | 0.32*** |
| Var*$P_2O_5$ | 7 | 17.63*** | 0.54*** | 0.54*** |
| Error | 30 | 0.00 | 0.00 | 0.00 |
| LSD (5%) | | 2.98 | 2.83 | 4.04 |
| CV (%) | | 7.40 | 5.33 | 5.41 |

Where: - *, **, ***: Significant at 0.05, 0.01 and .001 respectively, Var: Varieties, Var*NPSB: Interaction of Varieties with $P_2O_5$, Two-way interaction of varieties with P2O5 and DF: Degree of freedom, PH: Plant height, NPB: Number of primary branches and NSB: Number of secondary branches.

Appendix 3. Mean Square of Anova for Nodulation Parameters of Lentil

Mean squares

| Source of variation | DF | NND | NNDE | VNDW | NDFW | NNDW |
|---|---|---|---|---|---|---|
| Block | 2 | 0 | 0 | 0 | 0 | 0.08 |
| Var | 1 | 62.03*** | 61.6*** | 0.188*** | 317.8*** | 17.6*** |
| $P_2O_5$ | 3 | 7.36*** | 3.53*** | 0.2*** | 13.39*** | 5.016*** |
| Var*$P_2O_5$ | 7 | 1.69*** | 4.59*** | 0.18*** | 30.57*** | 8.26*** |
| Error | 30 | 0 | 0 | 0 | 0 | 0 |
| LSD (5%) | | 4.27 | 4.12 | 3.28 | 3.32 | 6.03 |
| CV (%) | | 3.2 | 3.46 | 1.37 | 7.09 | 4.33 |

Where: - *, **, ***: Significant at 0.05, 0.01 and .001 respectively, Var: Varieties, Var*$P_2O_5$: Interaction of Varieties with $P_2O_5$: Two-ways interaction of varieties with $P_2O_5$, DF: Degree of freedom, NN: Number of nodule per plant, NV, Nodule volume per plant, NFW: Nodule fresh weight and NDW: Nodule dry weight.

Appendix 4. Mean square of Anova for yield and yield components of lentil

| Source of variation | | Mean square | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | DF | NPP | NSPP | TSW | DBY | GY | STRW | HI |
| Block | 2 | 0.58 | 0 | 0 | 0.0190 | 0.00015 | 0.0157 | 52.697* |
| Var | 1 | 1046.04*** | 1.16*** | 42.48** | 8.43*** | 2.17*** | 2.06** | 2.47 |
| $P_2O_5$ | 3 | 68.11*** | 0.007*** | 1.38*** | 1.269** | 0.565** | 0.14** | 66** |
| Var*$P_2O_5$ | 7 | 21.65** | 0.0024*** | 1.84** | 0.190** | 0.52*** | 0.06** | 3.38 |
| Error | 30 | 0.24 | 0 | 0 | 0.0053 | 0.00198 | 0.0048 | 2.09 |
| LSD (5%) | | 0.53 | 3.7 | 8.86 | 0.08 | 0.04 | 0.077 | 1.6 |
| CV (%) | | 1.00 | 1.83 | 3.14 | 2.08 | 3.11 | 3.36 | 3.6 |

Where: - *, **, ***: Significant at 0.05, 0.01 and 0.001 respectively, Var: Varieties, Var*$P_2O_5$: Interaction of varieties with $P_2O_5$ Two-ways interaction of varieties with $P_2O_5$, NPP: Number of pods per plant, NSP: Number of seeds per pod, DBY: Dry Biomass yield, TSW: Thousand seed weight, HI: Harvest index, GY: Grain yield and STY: Straw yield.