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Effect of Nitrogen and Phosphorus Fertilization on the Growth, Yield and Quality of Potato (Solanum Tuberosum L.) At Debark; North Gondar Zone, Ethiopia

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BY

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JUNE, 2025

BAHIR DAR, ETHIOPIA

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Submitted to Department of Horticulture for Partial Fulfilment of the Requirement for Degree of Master of Science in Horticulture

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THESIS APROVAL SHEET

As members of the board of examiners of the Master of Sciences (MSc.) thesis open defense examination, we have read and evaluated this thesis prepared by **Mr. Akalu Mihretie** entitled **"Effect of Nitrogen and Phosphorus Fertilization on the Growth, Yield and Quality of Potato (*Solanum Tuberosum* L.) at Debark; North Gondar Zone, Ethiopia"** We hereby certify that, the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Science **(M.Sc.)** in Horticulture.

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DECLARATION

We hereby declare that the thesis entitled **"Effect of Nitrogen and Phosphorus Fertilization on the Growth, Yield and Quality of Potato** (*Solanum tuberosum* L.) **at Debark; North Gondar Zone, Ethiopia"** is the original work of **Akalu Mihretie**, conducted under the guidance and supervision of the undersigned advisor. This research has been submitted in partial fulfillment of the requirements for the award of a **Master of Science (MSc.) degree in Horticulture** in the **Graduate Program of the College of Agriculture and Environmental Sciences, Bahir Dar University**.

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DEDICATION

This thesis work is dedicated to my beloved father (Mihretie Tsigie) and mother (Gonie Molla) their affection, prayers, motivation, encouragement and consistent care for the success of my life.

ABBERVATIONS/ACRONYMS

ANOVA	Analysis of Variance
ATP	Adenosine Triphosphate
FAO	Food And Agricultural Organization Of United Nations
CSA	Central Statistics Agency
m.a.s.l	Meter Above Sea Level
TSP	Triple Supper Phosphate
CIMMYT	International Maize and Wheat Improvement Center
EARO	Ethiopian Agricultural Research Organization

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EFFECT OF NITROGEN AND PHOSPHORUS FERTILIZATION ON THE GROWTH, YIELD AND QUALITY OF POTATO (*Solanum tuberosum* L.) AT DEBARK; NORTH GONDAR ZONE, ETHIOPIA

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ABSTRACT

Potato is one of the most commonly cultivated crops in north Gondar. However, the productivity potato is very low as compared to the national average. Improper soil nutrient management is one of the major problems that contribute for this lower productivity. A field experiment was conducted at Debark university research site in 2024 irrigation season to determine the economically feasible rate of nitrogen and phosphorus fertilizer for the productivity of potato in the study area. Four levels of nitrogen (0, 92, 115 and 138 kg ha^{-1}) combined with four levels of phosphorus (0, 23, 34.5 and 46 kg ha^{-1}) were used as treatments. The experiment was laid out in randomly complete block design (RCBD) in factorial arrangement with three replications. The days to emergence, plant height, days to maturity, stem number, average tuber number, average tuber weight, marketable tuber yield, unmarketable tuber yield, total tuber yield, specific gravity, dry matter content and tuber starch content data was collected. R software version 4.4.2 were used for analysis of variance. The interaction of nitrogen and phosphorus was significantly affected the days to maturity, days to emergence and tuber starch content of potato. The plant height was very highly significantly ($p \le 0.001$) and highly significantly ($p \le 0.01$) affected by nitrogen and phosphorus respectively. Nitrogen fertilizer highly significantly ($p \le 0.01$) increased the marketable and total tuber yield of potato. Higher marketable and total tuber yield of 32.71 t and 34.32 t ha^{-1} () were obtained with the application of 138 kg h^{-1} N. Phosphorus also significantly ($p \le 0.05$) increased the tuber number, marketable yield and total tuber yield of potato. However, the interaction of nitrogen and phosphorus fertilization was not significant on the whole tested yield parameters except the unmarketable tuber yield. The highest dry matter content (23.43%) was recorded with 46 kg ha^{-1} of phosphorus application. Both nitrogen ($p \le 0.05$) and phosphorus ($p \le 0.01$) was significantly affected the specific gravity of potato. Phosphorus fertilization and the combined application with nitrogen were highly significantly ($p \le 0.001$) affected the tuber starch content. The regression analysis indicated that for every one unit increase in nitrogen fertilizer rate (kg) there was a corresponding 62 kg potato tuber yield increment. There was an increasing trend in the yield with increasing of phosphorus rate, however, it was less pronounced than nitrogen. For quality centered production 46 kg ha-1 P and 92 kg ha-1 N gives the highest dry matter content and specific gravity. The maximum net benefit of 613,173 ETB with acceptable marginal rate of return of 152.36% was achieved by the combined application of 138 kg ha^{-1} of nitrogen and 46 kg ha^{-1} phosphorus and it can be recommended for the most profitable production of the potato crop for Debark and the areas with similar agroecology's. In addition, the combined application of 115 kg N ha^{-1} and 34.5 kg P ha^{-1} offering net benefit of 602,644 ETB and an exceptionally high MRR of 8729.78%, it can be recommended as option for those with tight budget constraints.

Keywords; Economic analysis; Fertilizer rate optimization; Marginal rate of return, Specific gravity; Starch content

1. INTRODUCTION

1.1. Background and Justification

Potato (*Solanum tuberosum* L.*)*, is a highly versatile and widely consumed staple food. It is the fourth most consumed vegetable crop in the world (Haan & Rodriguez, 2016). The potato is a well-balanced food, providing a good ratio of proteins to calories. It also contains significant amounts of vitamins, particularly vitamin C, as well as minerals and trace elements (Helen Teshome, 2016). Potato tuber is not only a rich source of carbohydrates but also a valuable mineral resource for consumption. It meet the dietary needs of around half a billion people worldwide(Lakew Getaneh & Fanuel Laekemariam, 2021).

According to data from food and agricultural organization the global productivity of potatoes has been steadily increasing over the past few decades. In 2023, the total global potato production was estimated at around 383 million tons, with an average yield of 22.8 tons per hectare (FAO, 2024). The total cultivated area to potato worldwide is around 16.7 million hectares. The largest potato-producing countries in the world includes China, India, Russia, Ukraine, and the United States. These countries contributed significantly to the overall global potato production

Ethiopia is considered as one of the leading potatoes producing countries, particularly in Africa, due to its large potential for potato cultivation with significant portion of its arable land suitable for growing potatoes. The introduction of potatoes to Ethiopia can be traced back to 1858 when a German scientist named Schimper brought the crop to the country (Pankhurst, 1964). Initially, potato cultivation was limited to homesteads as a garden crop. However, there was a gradual increase in production at the end of the 19th century due to a prolonged famine in Ethiopia (Hadera Gebremedhin et al., 2008). Ethiopia's diverse agro-ecological zones make it suitable for potato cultivation, ranging from highlands to lowlands. This allows for year-round potato cultivation in different regions. Potato production plays a significant role in Ethiopia's agricultural sector, contributing to both food security and economic growth. It ranks first among root and tuber crops in terms of area coverage and total production. Despite this potential, only 2% of the suitable land for potato cultivation has been utilized so far (Tadele Amare et al., 2022).

Throughout the years, Ethiopia's potato output has grown steadily, mostly due to government assistance and rising consumer demand. The government has taken a number of inteventions to increase productivity and potato production, including training and granting access to better crops and technology (Brasesco et al., 2019). However, yield and productivity of potato are far below the world national average yield of 23 t ha^{-1} (Workat Sebnie, 2019). The current potato productivity in Ethiopia is less than 16.5 t ha^{-1} with the area coverage of 78,478 hectare and its total annual production is only about 1.3 million tone's (CSA, 2022).

The constraints for lower productivity of potato in Ethiopia are; poor agronomic practices, such as using inferior types, and rates of fertilizers, along with the use of worse-quality tubers are primary contributors, followed by the unavailability and high cost of seed tubers, lack of better and adaptable cultivars, and soil fertility issues. Additionally, irregular water supply, diseases and insect pests, inadequate marketing and post-harvest management facilities, drought, and the lack of improved characterization and ex situ conservation of potato genetic resources also significantly hinder productivity (Haverkort et al., 2012;Helen Teshome, 2016; Gedefa Moreda et al., 2022;Tamiru Ababa et al., 2023).

The poor production of potatoes in Ethiopia was thought to be primarily caused by the uneven usage of soil macronutrients in combination with a variety of potato cultivars (Mekides Mekashaw et al., 2020) . Nitrogen and phosphorus are among essential macronutrients for many physiological functions in the cell and consequently for plant growth and yield formation (Naumann et al., 2020).

The interaction effect of nitrogen and phosphorus fertilization on potato has been studied in the context of potato cultivation. Research has shown that this interaction significantly influences various aspects of potato growth, yield, and quality. The study conducted in the Wag-Lasta areas of Eastern Amhara, Ethiopia, investigated the effects of different nitrogen and phosphorus fertilizer rates on potato yield under irrigation conditions, revealing significant effects on plant height, marketable, and total yield. The highest yield of 45.55 t ha^{-1} was obtained, although phosphorus did not significantly impact plant height and unmarketable yield (Workat Sebnie et al., 2020). Another study conducted in northern highlands of Ethiopia investigated the optimum rate of nitrogen and phosphorus on tuber yield of potato; and found that the application of 92kg N ha^{-1} is recommended at Debark and similar agroecology. Even if application of P does not affect potato tuber yield, 23 kg ha^{-1} phosphorus fertilizer should be applied for soil fertility maintenance (Tamrat Worku et al., 2021). A study conducted in north western Ethiopia showed that more than 40 tons per hectare of potato could be attained, about four times the current productivity, through NP nutrient management (Tadele Amare et al., 2022). The study conducted by Workat Sebnie et al. (2021) found that, nitrogen and phosphorus could affect potato yield and related components. These findings underscore the importance of considering the specific interaction effects of NP fertilization on potato in order to optimize yield, quality, and other important traits in potato cultivation. The studies could be used to develop targeted and area-specific fertilizer recommendations and could investigate the impact of other factors such as soil fertility, and climate variability to improve potato productivity in the study area. Understanding and managing this interaction can contribute to improved agricultural practices and enhanced potato production.

1.2. Statement of the Problem

The North Gondar Zone in Ethiopia has a high potential for potato production. The area's suitable agro-ecology, including its altitude and temperature makes it favorable for potato cultivation. However, the potato productivity is very low (12 t ha^{-1}) in 2020/21 main cropping season as compared with the national and regional average productivity of potato (13.2 t ha^{-1} and 13.5 t ha^{-1}) respectively. It is also very low as compared to other zones in the region like South Gondar (14.9 t ha^{-1}); East Gojjam (14.4 t ha^{-1}); West Gojjam (14.0 t ha^{-1}) and Awi zone (17.4 t ha^{-1}) (CSA, 2022). For this comparatively lower productivity, different factors could be contributed. According to Debark Worda's agricultural office report, the primary barriers for the low productivity of potato in the area are inadequate agronomic practices. Among these incorrect agronomic practices improper application rate of fertilizers mainly phosphorus and nitrogen are the main ones. Potatoes are known to be nutrient-demanding crops, with a high requirement for nutrients such as nitrogen, phosphorus, and potassium (Yohannes Gelaye et al., 2022). Although earlier research has offered insightful information, it mostly focused on main rainy seasons and might not take into consideration the unique soil and climate conditions that exist during irrigation season. This study intends to create tailored fertilization strategies that maximize crop performance during this crucial period by examining the effects of NP macro nutrients on potato growth and yield under irrigated conditions.

1.3. Objective

1.3.1. General Objective

- The general objective of the study was to enhance potato production and productivity through an optimum NP fertilizer rate in Debark area.

1.3.2. Specific objectives

- To evaluate the effect of different NP fertilizer rates on the growth yield and quality of potato; and
- To determine an economic optimum NP fertilizer rates for potato production in Debark woreda.

2. LITRATURE REVIEW

2.1. Origin, Distribution and Agro-ecology of Potato

The potato crop originates from South America, particularly the central Andes region in Peru. It was domesticated by indigenous farming communities over 4,000 years ago (Merriam-Dictionary, 2024). The Spanish introduced the potato to Europe in the 16th century, bringing it from Peru to Spain around 1565. It then spread to other European countries such as Italy, France, Ireland, and England by the late 1500s. Potatoes are now grown worldwide, in over 100 countries, from sea level up to 4,700 meters above sea level. The crop is a staple food in many parts of the world, especially in Europe (notably northern and eastern Europe), Asia (China and India are leading producers), Africa, and the Americas (Sauer, 2017).

The potato is a herbaceous, frost-sensitive, short-day perennial plant typically cultivated as an annual for its starchy underground tubers. Biologically, it has a compound leaf structure and develops from true seeds or vegetatively through tubers, which are modified stem tissues functioning in nutrient storage and asexual reproduction. Ecologically, potatoes are best adapted to cool temperate climates and require well-drained, fertile soils with adequate moisture. Optimal growth occurs between 15–20°C, and tuber formation is sensitive to photoperiod and temperature—typically inhibited by high heat and extended daylight. The crop is moderately sensitive to drought and susceptible to numerous pests and diseases, especially late blight making it dependent on careful agronomic and ecological management (Hijmans & Spooner, 2001; FAO, 2008; Jansky et al., 2009).

Potatoes thrive under specific temperature, altitude, and soil conditions. The minimum temperature required for potato growth and development is 7°C, with the most rapid growth occurring at 21°C. For tuber initiation, the soil temperature should ideally be between 15 and 20°C, resulting in shorter stolon's and shoots. Productive potato-growing regions are typically found at mid-elevations, around 2,000–2,400 meters above sea level (Minda et al., 2018). Potatoes can be cultivated in a range of soils, including sands to clay loams, but they thrive best in well-structured soil with good water holding capacities. Ideal potato growing conditions involve deep to moderately deep, loose, and well-drained soils with a pH level ranging from 5.5 to 6.5. Altitude-wise, potatoes can be grown from sea level up to 4,700 meters above sea level. They are typically cultivated in temperate climates, preferring cool seasons without frost, while performing poorly in hot environments (Blom-Zandstra & Verhagen, 2015).

2.3. Status of Potato Production in Ethiopia

Ethiopia, one of Africa's top producers of potatoes, is possibly in a unique position to have the most potential land for potato cultivation. In Ethiopia, potato is grown in four major areas: the central, the eastern, the north-western and the southern regions, which together constitute approximately 83% of the potato farmers in the country (CSA, 2009). Over 70% of arable land and most of which located at an altitude of 1800-2500 m.a.s.l and receive an annual rainfall of more than 600-1200 mm makes the highest potential country for potato production (Hadera Gebremedhin et al., 2008). The major potato-producing regions, ranked by production levels, are Oromia, Amhara, and the Southern Nations Nationalities and Peoples (CSA, 2021).

Potato growing is expanding steadily, and the country's annual per capita consumption is estimated at just 5 kg (Chernet Worku, 2019). Potato is throughout the year, with the bulk production during the Belg season (March-June) and small production during the Meher season (July-October) in Ethiopia. The potato is currently cultivated across Ethiopia for local consumption since it is a significant food and income crop for Ethiopian farmers (Girma Legese, 2023).

During the months of limited food production from July to August, over 3.5 million smallholder farmers in Ethiopia's highlands cultivate potatoes, which have been shown to help reduce food insecurity (Teklemariam Tebabal, 2014). This practice occurs prior to the harvest of other grains, providing a crucial source of food during this time. The crops' capacity to adapt to diverse environmental circumstances and their short growing period making them a crucial source of revenue and food security (Ayalew Tewodros, 2014).

2.4. Role of Nutrient Fertilization in Potato Production

Nutrient fertilization plays a significant role in potato production, as it is essential for maintaining a healthy crop, optimizing tuber yield and quality, and minimizing undesirable impacts on the environment. Potatoes have a shallow root system and a relatively high demand for many nutrients, making a comprehensive nutrient management program essential. The impact of plant nutrients on potato yield is complex, and interactions with abiotic and biotic factors need to be considered. The most essential nutrients for potato growth include nitrogen, phosphorus, potassium, magnesium, calcium, and sulfur. The amount of nutrients removed by a potato crop is closely related to yield, and a comprehensive nutrient management program is necessary for maintaining a healthy potato crop and optimizing tuber yield and quality (Koch et al., 2020).

The results of various studies suggest that adopting proper nutrient management practices can lead to better potato yields and economic returns. For example, applying the right amount of nitrogen at the appropriate growth stages is crucial for achieving optimal yields (Alemayehu et al., 2015). Additionally, phosphorus fertilizer recommendations are often based on soil test levels and yield goals, and the use of enhanced efficiency fertilizers can improve nitrogen use efficiency (Hailu Gebru et al., 2017).

2.4.1. Role of nitrogen fertilizer on potato plant growth and productivity

Potato is typically grown on sandy loam and loam soils and require fertilizer for economical crop production. Nitrogen, phosphorous and potassium are the nutrients which are most commonly fertilized in potato production (Davenport et al., 2005). Nitrogen is one of the most crucial macronutrients for plant growth and biomass development (Koch et al., 2020). Plants can use nitrogen in different forms. Their major sources are ammonium (NH_4^+) and nitrate (NO_3^-) (Silva et al., 2013). Mandatory roles of nitrogen for plant growth are that it is a component of chlorophyll, amino acids, proteins, nucleic acids, coenzymes and membrane constituents (Ahmed et al., 2015). It plays a critical role in promoting plant growth, facilitating high yields, and ensuring optimal carbohydrate production in the leaves. This carbohydrate production is essential for the growth and development of tubers, ultimately impacting potato yield (Duguma Muleta & Chewaka Aga, 2019). N has the greatest impact on potato yield formation among all essential macronutrients (Silva et al., 2013). Potato yield can be divided into the three components; number of stems per square meter, number of tubers per stem and average tuber weight whereby nitrogen has the greatest impact on the average tuber weight (Morena et al., 1994). Nitrogen has a decisive impact on the number of emerging leaves and the rate of leaf expansion, and, therefore, on the canopy development of the plant (Ospina et al., 2014). Hence, it has a positive impact on photosynthesis efficiency by increasing the interception rate of radiation and photons (Mauromicale et al., 2006), and, as a consequence, on dry matter partitioning to the tubers, tuber bulking and, finally, on tuber yield formation (Ahmed et al., 2015). To facilitate proper growth and development, potatoes require an appropriate timing and quantity of nitrogen. During the stages of tuber initiation and tuber bulking, a potato crop typically utilizes 60 to 80 percent of its total nitrogen requirements (Jackson, 1999). Incorrect application of nitrogen can have negative consequences, including reduced specific gravity and dry matter content of the tubers, stunted growth, and premature vine death. Hence, effective nitrogen management is crucial for optimizing yield, quality, and profitability in potato crops (Koch et al., 2020).

2.4.2. Role of phosphorus fertilizer on potato plant growth and productivity

Phosphorus is another essential nutrient for potato plants, as it plays a significant role in various plant functions. It is particularly important for tuber formation, dry matter accumulation, and the development of strong potato stalks (Yohannes Gelaye et al., 2022). Phosphorus is also important for potato growth, and its application can increase tuber yield and quality. Phosphorous is required in relatively high amounts by the potato crop as compared to other crops. Phosphorus serves various functions in plant metabolism. Its most prominent role is cellular energy transfer by dephosphorylation of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) (Rosen et al., 2014). The potato plant can tolerate moderate phosphorus stress without any severe deficiency symptoms until photosynthesis and respiration being reduced to such an extent that carbohydrates accumulate. This becomes obvious in dark green to purple leaf discolorations, as described by Grant et al (2001). Compared to nitrogen, phosphorus is very immobile in soils as it is only poorly soluble. Thus, plant roots need to grow in the direction of phosphorus for its uptake. As only a few roots develop during the first growth period, it is a typical time for phosphorus deficiency to occur in potato (Hopkins et al., 2014).

Over-fertilizing potatoes with phosphorus can lead to several risks and negative consequences, including; reduced uptake of other nutrients such as iron and zinc, increased phosphorus concentration in plant tissues, environmental risks: such as water pollution and eutrophication of aquatic ecosystems, reduced yield and quality (Workat Sebnie et al., 2021 & Van Zeghbroeck et al., 2023). Phosphorus deficiency in potato production can have several detrimental effects, including reduced tuber development, lower yield, delayed maturity, and poor quality of the harvested potatoes. P-deficient plants produce very small tubers with higher sugar and slightly lower dry matter contents, and they tend to be overly mature at harvest. Phosphorus deficiencies result in poor root growth and stunted top growth, likely inducing zinc deficiency in commercial potato production fields (Ellsworth, 2003).

2.4.3. Effect of nitrogen on the growth, yield and yield components of potato

The effects of nitrogen were found to be statistically significant ($P < 0.01$), influencing plant growth (Firew Gebremariam et al., 2016). Increasing nitrogen from 0 to 168 kg ha^{-1} raised plant height from 34.00 cm to 88.67 cm. The lowest height (34.00 cm) was observed without nitrogen application. Plant height was increased by 23% as nitrogen level increased from zero to165 kg nitrogen ha^{-1} (Gebrie Getie et al., 2022). Increasing the rates of N from zero to the maximum has increased plant height by 46% over the control (Nimona Fufa et al., 2024a). Conversely (Desalegn Regassa et al., 2016) varied nitrogen rates had no significant effect on plant height. Increasing nitrogen application rates can delay the days to maturity of potatoes. A study found that increasing nitrogen from 0 to 165 kg ha^{-1} delayed physiological maturity by about 8.89 days (Gebrie Getie et al., 2022). This delay is attributed to nitrogen promoting vegetative growth, which can prolong the plant's life cycle. While excessive nitrogen delays maturity, optimal levels are necessary for healthy plant growth and tuber development. Proper nitrogen application can support efficient tuber formation without significantly extending the maturity period. Similarly, Nimona Fufa et al. (2024a), and Fantaw Solomon et al. (2019), who observed that the increasing of nitrogen levels showed a significant effect on days to physiological maturity. When compared to the unfertilized treatment, the highest fertilized rate delayed flowering and maturity. In addition (Israel Zewide, 2012) also reported that, increasing nitrogen fertilization from zero to 165 kg ha^{-1} delays the days to maturity by 14%.

Various studies revealed that, nitrogen fertilizer has a significant effect on the yield of potato. According to (Nimona Fufa et al., 2024b), the average number of tubers per hill grew in proportion to the amount of fertilizer used. Similarly Firew Gebremariam et al., (2016), who reported that increasing nitrogen application up to 56 kg N ha^{-1} positively influences the average tuber number per hill. Beyond this rate, tuber numbers tend to decline, indicating a threshold effect where excessive nitrogen may inhibit tuber formation due to increased aboveground biomass. The author Gebrie Getie et al. (2022), also revealed increased nitrogen fertilization significantly increased tuber number of potato.

Marketable tuber yield refers to the portion of the harvested crop that meets the quality and size standards for sale in the market. It excludes damaged, diseased, or undersized tubers that are not suitable for commercial use. The marketable yield depends on several factors, including the potato variety, growing conditions, pest and disease management, and harvesting practices. Studies have shown that applying nitrogen fertilizer at optimal level significantly enhances potato yields. For example, increasing nitrogen from 0 to 138 kg ha^{-1} increased yield by up to 74.61% in some cases (Nimona Fufa et al., 2024b). Gebrie Getie et al. (2022), reported that the maximum marketable yield (30.7 t ha^{-1}) and minimum unmarketable yield was obtained at the plot treated with higher nitrogen (110 kg ha^{-1}).

Unmarketable tuber yield refers to tubers that are not suitable for sale due to factors like disease, deformation, or being too small (typically less than 20 g). This yield component is influenced by several factors, including variety, seed tuber size, and fertilizer application. While nitrogen fertilization primarily increases marketable tuber yield, it can indirectly affect unmarketable tubers by promoting healthier plant growth. However, excessive nitrogen can lead to increased vegetative growth at the expense of tuber quality (Wakjira Negero, 2017 & (Milkias Kukra & Abrham Shumbulo, 2022). High nitrogen concentrations, especially beyond optimal levels, can lead to physiological problems in tubers, contributing to higher levels of unmarketable produce (Firew Gebremariam et al., 2016).

Total tuber yield of potato refers to the total weight of potatoes harvested from a specific area, usually measured in tons per hectare. It is a crucial indicator of the productivity and economic viability of potato cultivation. High tuber yield is desirable for farmers as it directly impacts profitability and food supply. Nutrient availability is one of the factors affecting total tuber yield of potato. Adequate levels of essential nutrients, particularly nitrogen, phosphorus, and potassium, are critical for optimal growth and tuber formation (Tadele Amare et al., 2022). Israel Zewide et al. (2012) reported that, increasing nitrogen application rates resulted in an increase in tuber yield from 23.75 to 38 t ha^{-1}. Application of 110 nitrogen ha^{-1} increased tuber yields by 86% as compared to control (Gebrie Getie et al., 2022). Increasing the rate of nitrogen alone will increase potato tuber yield by 74.61% (Nimona Fufa et al., 2024b). Increasing nitrogen application from 0 to 56 kg ha^{-1} enhances total tuber yield across all phosphorus rates (Firew Gebremariam et al., 2016).

Nitrogen is crucial for vegetative growth, and adequate nitrogen can improve leaf development, which in turn enhances photosynthesis and can lead to larger tuber sizes. According to Isreal Zewide et al. (2012), increased application rate of nitrogen from 0-165 kg ha^{-1} increased average tuber weight by 22.43% as compared to the control. Similarly Wakjira Negero, (2017), discovered that the unfertilized plot had the lowest tuber weight, whereas the plot fertilized with more nitrogen had the highest. In addition, Gebrie Getie et al. (2022), reported that the increasing of nitrogen significantly increased average tuber weight of potato.

Specific gravity and dry matter content are critical factors in determining the quality and suitability of potato tubers for processing, especially in the production of potato chips. Dry matter content of potato refers to the solid content remaining after the removal of water, which typically constitutes about 15% to 25% of a potato's total weight, depending on various factors such as variety, maturity and growing conditions; environmental factors such as soil type, climate, and agricultural practices (like irrigation and fertilization) also play significant roles in determining dry matter accumulation (Mohamed et al., 2017). The water content in potatoes generally ranges from 75% to 85%, making the dry matter a crucial component for assessing quality and nutritional value (Norell et al., 2016 & Mohamed et al., 2017). Higher dry matter content is often associated with better processing qualities, such as crispiness and color in fried products (Islam et al., 2022). Dry matter contains essential nutrients, including carbohydrates, proteins, and vitamins, making it a key indicator of the potato's overall nutritional profile (Mohammed, 2016).

Nitrogen fertilization has been shown to reduce both tuber specific gravity and dry matter content. This is likely due to nitrogen promoting vegetative growth, which can lead to a decrease in tuberization and, consequently, lower dry matter accumulation in tubers (Milkias Kukra & Abrham Shumbulo, 2022). Nitrogen promotes shoot growth, which can delay tuber maturity and reduce the proportion of dry matter allocated to tubers (Zelalem Ayichew et al., 2009). The overall reduction in tuber dray matter content by nitrogen fertilization may be related to the effect of nitrogen on gibberellin biosynthesis activities, which directly affect plant development and dry matter accumulation (Tilahun Alemayehu et al., 2015). The dry matter content increased from 17.37% to 17.80% with 56 kg ha^{-1} of nitrogen but decreased to 11.98% when nitrogen was increased to 168 kg ha^{-1} (Firew Gebremariam et al., 2016).

Increases in nitrogen application (beyond 56 kg ha^{-1}) led to a reduction in specific gravity (Firew Gebremariam et al., 2016). The specific gravity was significantly affected by the level of nitrogen fertilizer (Milkias Kukra & Abrham Shumbulo, 2022).

2.4.4. Effect of phosphorus on the growth, yield and yield components of potato

According to (Firew Gebremariam et al., 2016) the effects of phosphorus were found to be statistically significant ($P < 0.01$), influencing plant growth. Increasing phosphorus from 0 to 138 kg P2O5 ha^{-1} increased plant height from 34.00 cm to 64.00 cm. Similarly, the application of phosphorus fertilizers significantly affects the plant height of potatoes, as demonstrated in studies conducted at two sites: Kechin Abeba and Woleh (Workat Sebnie et al., 2020). Similarly, (Desalegn Regassa et al., 2016) found that phosphorus treatment had a considerable impact on plant height.

Increasing of phosphorus application significantly reduced the day to 50% maturity of the potato crop (Firew Gebremariam et al., 2016). On the other hand, Nimona Fufa et al. (2024a), and Fantaw Solomon et al. (2019), who observed that phosphorus levels were found to be non-significant.

Application of different rates of phosphorus fertilizer has a considerable effect on the quantity of tubers per hill. The persistence of photosynthesis and active leaves for longer periods of time may account for the increase in the overall number of tubers per hill as fertilizer levels rise. Therefore, more tubers may have been initiated as a result of increased photosynthetic activity and photosynthesis moving to the sink. Significant increases in tuber numbers observed when phosphorus rates are increased (Desalegn Regassa et al., 2016 & Firew Gebremariam et al., 2016).

The marketable yield of potatoes is significantly influenced by the availability and management of phosphorus (P), as this nutrient play critical roles in plant growth, tuber development, and overall crop productivity. Proper application of phosphorus can enhance both the quantity and quality of marketable tubers. According to Zelalem Ayichew et al. (2009), application of phosphorus up to 60 kg ha^{-1} increased the marketable yield by about 66% over the control. Similarly, Fantaw Solomon et al. (2019), also reported that the marketable tuber number was significantly affected by phosphorus fertilization.

Phosphorus and other nutrients like potassium can influence tuber health and quality, potentially reducing unmarketable tuber yield by promoting more robust tuber development (Babaji et al., 2009). As reported by Workat Sebnie et al. (2020), the application of phosphorus fertilizer significantly affects the unmarketable yield of potatoes.

Increasing the rate of phosphorous increased potato tuber yield by 72.53% over no fertilizer treatment (Nimona Fufa et al., 2024b). The authors, (Mulubrhan, 2004, Israel Zewide et al., 2012 & Tadele Amare et al. 2022), confirmed increased phosphorus fertilization increases total tuber yield of potato. Adequate phosphorus can enhance root development and the early stages of tuber formation, leading to larger tuber weights and improved overall yield. Increasing application of phosphorus increased average tuber weight and showed a consistent increasing trend with increasing dose of phosphorus fertilizer rate (Isreal Zewide et al., 2012). A lack of phosphorus can hinder tuber development, resulting in smaller and less marketable potatoes. The application of phosphorus significantly enhanced tuber weight (Desalegn Regassa et al., 2016).

The dry matter content of potatoes can be influenced by the application of phosphorus fertilizers, though the effects vary depending on the specific conditions and rates of application. The dry matter content also improved with phosphorus, increasing from 10.66% at 0 kg $P2O5$ ha^{-1} to 16.74% at 138 kg $P2O5$ ha^{-1}. This increase is attributed to phosphorus's role in underground biomass formation, which positively impacts dry matter accumulation (Firew Gebremariam et al., 2016). Increased phosphorus fertilization significantly increased specific gravity of potato (Maier et al., 1994). According to Isreal Zewide et al. (2016), phosphorus application had a significant impact on potato tuber specific gravity.

2.4.5. The interaction effect of nitrogen and phosphorus on the growth yield and yield components of potato

Various studies revealed that, nitrogen and phosphorus fertilizers had a significant effect on the growth and yield of potato. The application of nitrogen and phosphorus as well as their interaction significantly influence the plant height (Fantaw Solomon et al., 2019). Similarly, the combined application of nitrogen and phosphorus significantly increased plant height of potato (Nimona Fufa et al., 2024b). The application of 165 kg N with 20 kg P increased plant height by 24 cm compared to the control (51 cm), showing that nitrogen and phosphorus together promote vegetative growth (Isreal Zewide et al., 2012).

The interaction between nitrogen and phosphorus is crucial for maximizing potato yields. Balanced application of these nutrients is essential for achieving optimal growth and yield parameters (Firew Gebremariam et al., 2016). According to Fantaw Solomon et al. (2019), the combined application of 165 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorus increased the marketable yield by 141% over the unfertilized plot. Nitrogen and phosphorus showed synergistic effects on the yield. Increasing nitrogen from 0 to 165 kg ha^{-1} significantly increased fresh biomass and total tuber yield. The highest marketable tuber yields were obtained with combined application of 165 kg N ha^{-1} and 180 kg P2O5 ha^{-1}, although yields at 110 kg N ha^{-1} with 180 kg P2O5 ha^{-1} were not significantly different. This synergy suggests that phosphorus enhances nitrogen use efficiency, and both nutrients together maximize yield (Isreal Zewide et al., 2012). On the other hand Nimona Fufa et al. (2024b), reported that, the interaction of nitrogen and phosphorus was not significant on the marketable yield of potato.

The study conducted in north-western Ethiopia found that the use of nitrogen and phosphorus fertilizers had a significant impact on potato yield. The yield of potato increased by more than two-fold when nitrogen and phosphorus fertilizers were applied compared to no fertilizer application. The response to nitrogen was stronger than the response to phosphorus (Tadele Amare et al., 2022). The highest potato yield was achieved with the application of 138 kg N ha^{-1} combined with 46 kg P_2O_5 ha^{-1}. The study concluded that soil fertility management through nitrogen and phosphorus fertilizers can greatly improve potato productivity in the region (Tadele Amare et al., 2022). The interaction between nitrogen and phosphorus had a significant influence on tuber yield (Hailu Gebru et al., 2017). In studies conducted in the Woleh and Kechin Abeba irrigation command areas, both fertilizers were found to enhance the total and marketable yield of potatoes (Workat Sebnie et al., 2020). Increasing nitrogen application from 0 to 56 kg ha^{-1} enhances total tuber yield across all phosphorus rates (Firew Gebremariam et al., 2016). Additionally, there was a notable interaction effect between nitrogen and phosphorus on tuber weight (Desalegn Regassa et al., 2016). Increased nitrogen and phosphorus significantly increased specific gravity of potato (Maier et al., 1994). Phosphorus application generally improved quality attributes, but high phosphorus rates sometimes reduced specific gravity depending on variety and location. Specific gravity was positively correlated with dry matter content and starch content. However, increasing nitrogen rates tended to decrease specific gravity (Isreal Zewide et al., 2012), (Arakit et al., 2021) and (Nyiraneza et al ., 2021).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study was conducted at Debark in 2024 under irrigation season which is in the highland part of the Amhara regional state with an elevation of 2800 m.a.s.l. The longitude and latitude the area is 37.8989689 and 13.1509414 respectively. An average annual rainfall of 800 to 974 mm and an average minimum and maximum temperature 10 and 22 ◦C respectively. The main rainy season is from June to September with the maximum rain, about 70–80%, received in July and August months (Anteneh Agezew et al., 2023). The farming activity is subsistence mixed farming where crop and animal production dominates the system. Major crops grown in the study area include barley (*Hordeum vulgare*), wheat (*Triticum spp.*), faba bean (*Vicia faba*), field pea (*Pisum sativum*), and flax (*Linum usitatissimum*). Vegetables like potatoes (*Solanum tuberosum*), garlic (*Allium sativum*), and leafy greens. Cattle, horses, donkeys, mules, sheep,

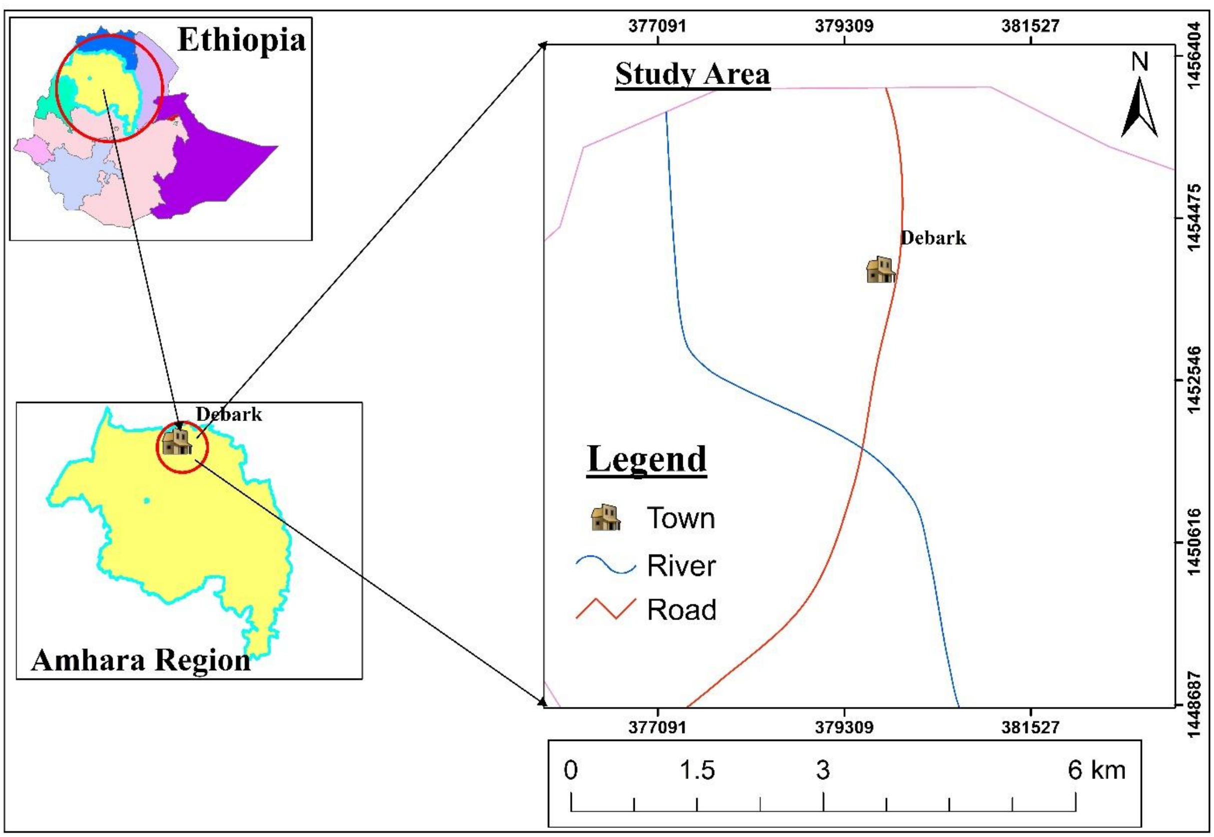

Figure 1. Map of the study area

goats, chickens, and bees are major parts of the farming system (Belay Tefera et al., 2014).

3.2. Experimental Materials

In the experiment urea (46% N) and triple super phosphate,TSP (T46% P_2O_5) was used as nitrogen and phosphorus sources respectively. Belete potato variety was used for testing, and the seed tubers were collected from Debark University. The tubers were stored in good condition (at a cool temperature, ideally between 10°C to 12°C, dark environment and well air circulated storage), well sprouted, same harvest, medium in size (>50mm in diameter and >100g in weight), which is regarded as the ideal size for planting in terms of seed size distribution. Furthermore, the seeds used for plantin materils were general healthy and free of any defect.

3.3. Treatments and Experimental Design

The experiment consisted of four levels of nitrogen (0, 92, 115, and 138 kg N ha^{-1}), combined with four levels of phosphorus (0, 23, 34.5 and 46 kg P ha^{-1}). The experiment was followed a randomized complete block design in factorial arrangement. Each treatment was replicated three times.

3.4. Experimental Procedures and Managements

Experimental land was repeatedly ploughed to achieve a fine, well-leveled seedbed suitable for tuber development. Seed tubers were planted at the recommended spacing to ensure uniform emergence and growth. The gross plot size were 3m in width (consisting of 4 rows) and 2.4m in length. The potato seeds were spaced 30 cm apart within each row, with a row spacing of 75 cm. To optimize nutrient application, the whole TSP was applied once at the time of planting while nitrogen fertilizer was applied in splits: 50% of the dose during planting and the remaining half during at flowering. The experiment was conducted in the off-season (under irrigation) in 2023/2024 irrigation season. Irrigation water was applied at 10 days interval by furrow irrigation system (Schmitter et al., 2017). The furrows were designed with uniform spacing and depth to allow for even water distribution while maintaining a consistent slope throughout the system. Weed control was performed manually at regular intervals to minimize competition for nutrients, light, and moisture. Recommended cultural practices outlined by the Ethiopia agricultural research organization (EARO) in 2004 for effective crop management were implemented throughout the experimentation period. Harvesting was conducted at full physiological maturity to ensure good tuber quality and yield measurement accuracy. Tubers were carefully handled post-harvest and stored under diffused light conditions to maintain quality and viability for further evaluation.

3.4.2. Data collection

3.4.2.1. Growth parameters

Days to emergence: The number of days elapsed from planting to 50% of the plants emerged from the soil,

Days to maturity: It refer to the number of days to reach a stage where it is ready for harvest. It was recorded when 50% of the plants in each plot were ready for harvest, indicated by the senescence of the haulms, with the count starting from emergence to maturity.

Plant height: It was measured by selecting eight plants randomly from the net plot area starting from the soil surface to the apex of the plant.

3.4.2.2. Yield and yield related parameters

Average tuber number per hill: refers to the total count of tubers produced in a single plant. It was determined by counting all tubers harvested from sampled twelve plants and divided by the number of samples.

Average tuber weight: was calculated by dividing the total tuber yield by the mean tuber number per hill (twelve plants was selected).

Marketable tuber yield: refers to the quantity of potato tubers harvested in the net plot area that meet specific quality standards focuses on tubers that are of desirable size (>20g), and free from defects and diseases. It was determined in tons per hectare.

Unmarketable tuber yield: refers to the weight of tubers that do not meet market standards including tubers with physical defects, diseases, insect infestations, and under-sized (<20g), It was expressed in percent.

Total tuber yield: It was recorded by summing the weights of both marketable and unmarketable tubers from the central rows, also expressed in tons per hectare.

3.4.2.3. Quality parameters

Specific gravity; It is a measure of the density of the tubers in air as compared to water. Five kg of tubers was weighted in air and then in water and the value was calculated using the formula developed by Gould (1995);

$$Specific\ gravity = (Weight\ in\ air)/(Weight\ in\ air - Weight\ in\ water)$$

Dry matter content (%): is percentage measures the amount of solid matter in the tubers after removing water. It was assessed by chopping five tubers into small cubes, drying two sub-samples of 200 grams each in an oven at 80°C for 72 hours until a constant weight was achieved. Then the percentage of dry matter content was calculated using the following formula according to De Haan et al. (2014).

$$:Dry\ matter\ (\%) = \left(\frac{Dry\ weight}{Fresh\ weight}\right) x100$$

Starch content (g/100g): It was derived from the specific gravity using the the following formula developed by Talburt & Smith (1959):

$$Starch(\%) = 17.546 + 199.07x(specific\ gravity - 1.0988)$$

3.4.3. Data analysis

All data was subjected to analysis of variances with R statistical software (R Core Team, 2023). Prior to conducting the ANOVA, the assumptions of normality were assessed using the Shapiro-Wilk were satisfied. The mean effects of the treatments were compared using the least significant difference test at a 0.05 probability level (Gomez & Gomez, 1984). To evaluate the association of traits correlation analysis was conducted for the parameters days to emergence, plant height, days to maturity, stem number, tuber number, average tuber weight, marketable tuber yield, unmarketable tuber yield, total tuber yield, dry matter content, tuber starch content and specific gravity and following it for traits (marketable tuber yield, total tuber yield, plant height, tuber number, dry matter content, tuber starch content, stem number) having strong correlation with the predictor variables (nitrogen and phosphorus fertilizer rates) simple linear regression analysis was conducted using the lm function of R statistical package.

3.4.3. Partial budget analysis

A partial budget analysis was performed to identify the economically optimal rates of nitrogen and phosphorus (NP) fertilizer for potato production. This analysis was done based on the CIMMYT guideline CIMMYT, (1988) which indicated that applying nutrients with a marginal rate of return above the minimum level of 100% is considered economically viable. For the partial budget analysis, the prevailing local market prices were used to reflect realistic economic conditions faced by farmers. The cost of urea was considered at 44.40 ETB/kg, while the cost of NPS fertilizer was 43.20 ETB/kg. Although TSP was used during the experimental phase, NPS was substituted in the economic analysis due to its more common use among farmers in the area, ensuring greater relevance and applicability of the results. The farm gate price of potato was taken as 20 ETB/kg. To reflect realistic farm level performance and reduce bias from controlled experimental conditions, the marketable yield was adjusted downward by 10% during the partial budget analysis, following standard practice.

$$AjY = AvY * 0.9$$

$$GB = AjY * Farm\ get\ price\ of\ tuber\ yield$$

$$NB = GB - TVC$$

$$MRR\% = \frac{\Delta \text{NB}}{\Delta \text{VC}} * 100$$

Where:

AjY=adjusted yield (it is the average yield adjusted downward by a 10%), AvY=average yield of potato tuber, TVC=total variable cost, GB=gross benefit, NB=net benefit, MRR%=marginal rate of return, ΔNB=change in net benefit, ΔVC=change in variable cost.

3.4.1. Soil Physico-chemical parameter analysis

Baseline information about the fertility status of the experimental site is helpful to determine the required artificial fertilizer rates. Accordingly, a composite soil sample was prepared from sub-samples collected from 0 to 20 cm depths using an auger. The composite soil samples were labeled and transported to the laboratory in plastic bags for further processing and analysis, which was carried out as per standard procedures. Soil analysis was carried out at Adet agricultural research institute soil laboratory. Soil pH was measured using a glass combination pH meter in the supernatant of a 1:2.5 soil to water ratio (Chopra & Kanwar, 1976). This was done to measure the intensity of soil acidity in soil solution. The organic matter (OM) content (%) of the soils was determined following the wet digestion method as described by Walkley & Black (1934). The total nitrogen (N) content of the soil was determined through a digestion, distillation, and titration procedure of the Kjeldahl method (Alford, 1952). Available phosphorus was determined by Olsen method using ammonium fluoride as an extractant and measuring the concentration of the nutrients at 880 nm (Bray & Kurtz, 1945).The cation exchange capacity (CEC) was measured after leaching the ammonium acetate extracted soil samples with a 10% sodium chloride solution. The amount of ammonium ion in the percolate was determined by the Kjeldahl procedure and reported as cation exchange capacity (Chapman, 1965). The result of soil analysis is presented below.

The soil sample collected from the experimental site was analyzed the results indicated that the soil has a clay texture, with 52% clay, 41% sand, and 7% silt (Table 1). The high clay content suggests that the soil has good water and nutrient holding capacity but may have limited drainage and aeration. The pH of 5.40 classifies the soil as moderately acidic (Asnakew et al., 1991). The organic carbon (OC) content of 1.85% is rated as medium (Asnakew et al., 1991), indicating a moderate level of soil organic matter that can support microbial activity and soil structure. However, the total nitrogen (TN) content of 0.105% and available phosphorus (AvP) of 4.30 mg kg^{-1} are both rated as low (Landon et al. 2004), suggesting potential deficiencies in these essential nutrients that may need to be addressed through fertilization for improved crop yields. The cation exchange capacity (CEC) of 26.96 cmolc kg^{-1} is rated as high, reflecting the soil's ability to retain and supply cations such as calcium, magnesium, and potassium, which is beneficial for plant growth. The high CEC is likely due to the dominant clay fraction and moderate organic matter content. However, the low levels of nitrogen and phosphorus may limit plant productivity despite the favorable CEC.

Table 1; The physicochemical property of the experimental site before planting.

Soil property	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Textural class**	**PH (H_2O)**	**OC (%)**	**TN (%)**	**AvP. (mg kg^{-1})**	**CEC (cmol$_c$ kg^{-1}**
Value	41	7	52		5.40	1.85	0.105	4.30	26.96
Rating				Clay	Moderately acidic	Medium	Low	Low	High
References				(Hazelton & Murphy, 2016)	(Asnakew et al., 1991)	(Asnakew et al., 1991)		(Asnakew et al., 1991)	Landon *et al*. (2004)

4. RESULT AND DISCUSSION

4.2. Effect of Nitrogen and Phosphorus on Phenological and Growth Parameters of Potato

4.2.1. Days to emergence of potato

The ANOVA result revealed that both nitrogen and phosphorus were not significantly ($P>0.05$) affect the days to emergence of potato. Whereas the interaction effect showed a significant ($P\leq0.01$) difference on the days of emergence (Appendix table 1). Significantly late and early emergency days of 25.33 and 19.66 was recorded with the interaction of 115 kg ha^{-1} N and 23 kg ha^{-1} P_2O_5 and 0 N & 34.5 kg ha^{-1} P_2O_5, respectively (Figure 2). The current result partially agreed with (Firew Gebremariam et al., 2016) reported that the main effect and combined application of nitrogen and phosphorus significantly affected the days to emergence of potato. While it contradicts with (Milkias Kukra & Abrham Shumbulo, 2022) discovered that nitrogen and phosphorus fertilization has no significant effect on the days to emergence.

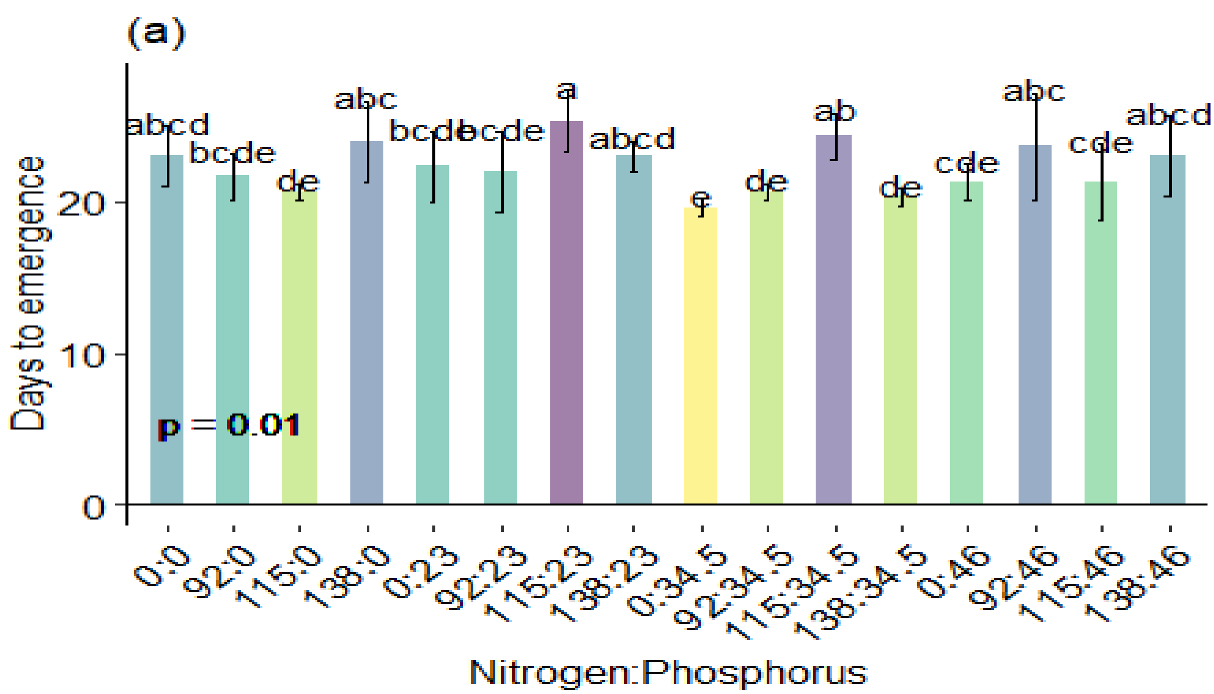

Figure 2. Mean of interaction effect of nitrogen and phosphorus on the days to emergence of potato

4.2.2. Days to maturity

Both of main factors and their interaction were significantly affected the days to maturity of potato. Nitrogen was very highly significantly ($P \leq 0.001$), phosphorus highly significantly ($P \leq 0.01$) and the interaction of the two factors significantly ($P \leq 0.05$) affected day to maturity (Appendix table 1). The increased application of nitrogen significantly increases days required to maturity (Table 3). The findings indicate significantly the longest maturity period of 120.66 days was observed at higher nitrogen and phosphorus interaction of 138 kg ha^{-1} and 46 kg ha^{-1}. The significant main effects of nitrogen and phosphorus suggest that both nutrients contribute to prolonged maturity when applied in higher doses. The significant interaction ($P \leq 0.01$) implies that the combined application of nitrogen and phosphorus has a synergistic effect in delaying maturity beyond their individual impacts. Nitrogen promotes vegetative growth (leaf and stem development), and phosphorus supports energy transfer (ATP) and root development. Together, they may extend the growth period before the plant shifts fully to tuber bulking and maturation. In addition, the significant N×P interaction ($p < 0.05$) suggests that the impact of nitrogen on potato maturity is significantly influenced by phosphorus availability. Long maturity period was only achieved when both nutrients were present in balanced amounts, confirming their synergistic role in days to maturity. That means the effect of nitrogen is dependent with availability of phosphorus i.e. adequate phosphorus enhance nitrogen uptake and nitrogen use efficiency. Similarly, Fantaw Solomon et al. (2019), reported days to maturity was prolonged by 9 days when 165 kg ha^{-1} nitrogen with 90 and 45 kg ha^{-1} phosphorous fertilizer were applied as compared to unfertilized plant. This result contradicts with the finding of (Nimona Fufa et al., 2024b) and (Firew Gebremariam et al., 2016) who reported that the interaction of nitrogen and phosphorus was not significant on the days to maturity.

Early maturity is generally considered a desirable trait in potato production, as it allows for earlier harvesting, reduced exposure to late-season pests and diseases, and the possibility of growing a second crop within the same season. In the present study, the earliest maturity (110 days) was recorded in the control plot, which did not receive nitrogen and phosphorus fertilizers. This result may be attributed to the limited nutrient availability in the control plot, which likely accelerated the plant's physiological development and forced it to complete its life cycle more rapidly. While early maturity can be advantageous, it is often associated with reduced biomass accumulation and lower tuber yield, suggesting a trade-off between earliness and productivity.

Table 2: Mean of the interaction effect of nitrogen and phosphorus rates on days to maturity of potato.

Treatments		**Parameter**
N	**P**	**DM**
0	**0**	110.3[i]
92	**0**	113.33[g]
115	**0**	118.66[b]
138	**0**	115.66[e]
0	**23**	110.66[i]
92	**23**	114.33[f]
115	**23**	117[d]
138	**23**	117[d]
0	**34.5**	110.66[i]
92	**34.5**	115.33[e]
115	**34.5**	117.66[cd]
138	**34.5**	120[a]
0	**46**	112[h]
92	**46**	115.66[e]
115	**46**	118.33[bc]
138	**46**	120.66[a]
Sign. Level		**
CV (%)		**1.93**
LSD		**0.44**

DM-days to maturity, ns-non-significant, *-significant, **-highly significant,

4.2.2. Plant height of potato

Plant height was highly significantly ($P \leq 0.01$) and significantly ($P \leq 0.05$) affected by both nitrogen and phosphorus fertilization respectively. However, the interaction of nitrogen and phosphorus was not significant ($P > 0.05$) affect plant height (Appendix table 1). The increasing of nitrogen from 0 to 138 showed progressive increment in plant height of potato. The highest mean plant height of 66.85cm was obtained with maximum nitrogen (138 kg ha^{-1}) application followed by 65.42cm with 115 kg ha^{-1} statistically in par. The lowest plant height of 51.98cm was obtained in the control plot (Figure 3). This is attributed to adequate nitrogen supply promotes vigorous vegetative growth, resulting in taller plants. Nitrogen is vital for synthesizing amino acids, proteins, and enzymes that drive cell division (meristematic activity) and elongation. This directly increases stem height and leaf expansion. Without supplemental nitrogen, plants rely on soil-native nitrogen, which is often insufficient for optimal growth. This restricts protein synthesis, slows cell division, and reduces photosynthetic capacity, leading to stunted stems and smaller leaves.

The current finding was in agreement with Firew Gebremariam et al. (2016), Workat Sebnie et al. (2021), and Nimona Fufa et al. (2024), who reported that nitrogen application significantly increases potato plant height. Conversely, Desalegn Regassa et al. (2016), reported that plant height was not significantly affected by nitrogen fertilization.

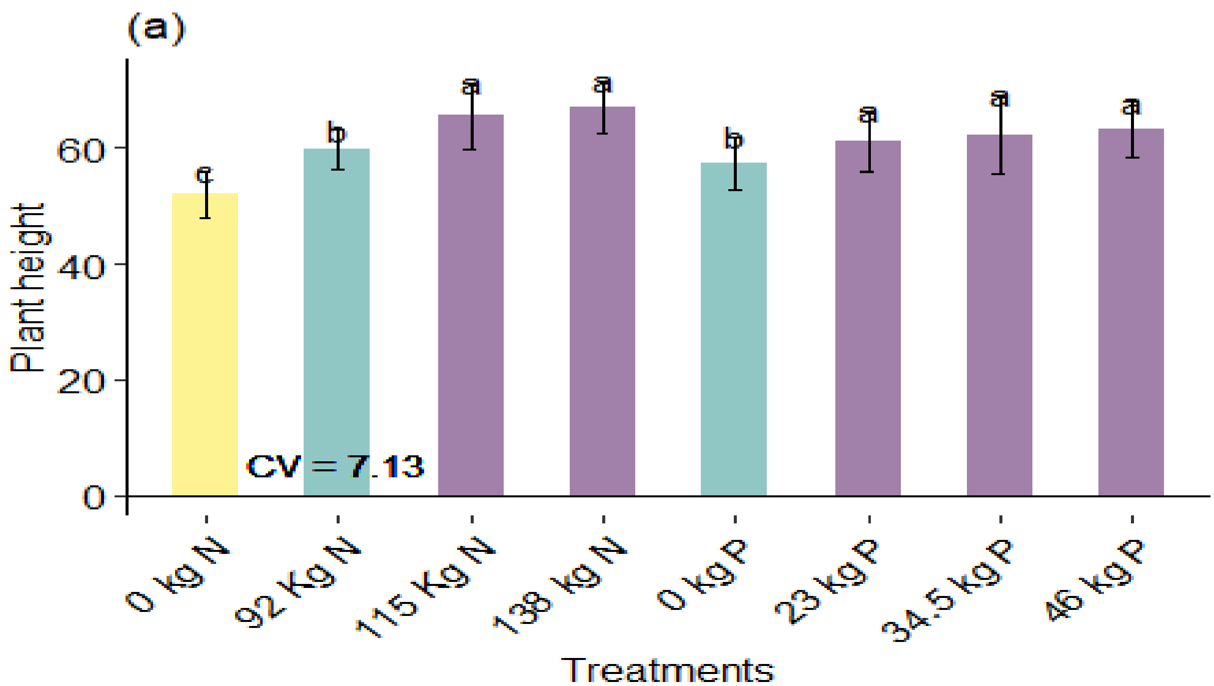

Figure 3. Mean of the effect of nitrogen and phosphorus on plant height of potato

Phosphorus also significantly affect the plant height of potato. Although the highest plant height (63.11cm) was recorded from the plot fertilized with 46 kg ha^{-1} of phosphorus, but it was not significantly different with 34.5 kg ha^{-1}(62.28cm) and 23 kg ha^{-1} (61.1cm) (Figure 3). The plant height of the plot unfertilized with phosphorus was 9.18% lower than the plot fertilized with higher phosphorus. This is due to the fact that phosphorus is crucial for early root and shoot development, indirectly supporting plant height. This result in line with Desalegn Regassa et al. (2016), and Fantaw Solomon et al. (2019), who reported that increased application of phosphorus increases the plant height of potato. Similarly, Zelalem Ayichew et al. (2009), reported that increasing of nitrogen and phosphorus significantly increased the plant height of potato.

4.2.3. Stem number per plant

The analysis of variance indicated that, nitrogen and phosphorus was significantly ($p \leq 0.05$) and highly significantly ($p \leq 0.01$) affected the stem number per plant respectively. Whereas the effect of the interaction of the two factors were not significantly ($P>0.05$) influenced the stem number (Appendix table 1). The highest mean stem number (4.84) was recorded from the plot fertilized by 46 kg ha^{-1} of phosphorus and the lowest stem number (4.0) was recorded at the control plot (Figure 4). The highest stem number with the increasing of phosphorus may be due to phosphorus availability promotes root development and overall plant vigor, enhancing the plant's ability to produce multiple stems. Phosphorus is a key component of ATP (adenosine triphosphate), the energy currency of plants. Adequate phosphorus ensures sufficient energy for cell division and meristematic activity, which drives the formation of new stems (tillers). In agreement with this finding Yohannes Gelaye et al. (2022) reported that phosphorus fertilization showed a significant difference on the stem number of potato.

The application combined application of nitrogen with phosphorus was not statistically significant on the stem number (Appendix table 1). Although the highest application of phosphorus and nitrogen together raises the stem number, the difference was not statistically significant. In agreement with this result (Fantaw Solomon et al. (2019) reported that, the application of nitrogen significantly affects the stem number of potato rather than phosphorus and their interaction. On the other hand (Nimona Fufa et al. (2024a), reported that, the application of both nitrogen and phosphorus and their interaction did not affect the stem number per hill of potato.

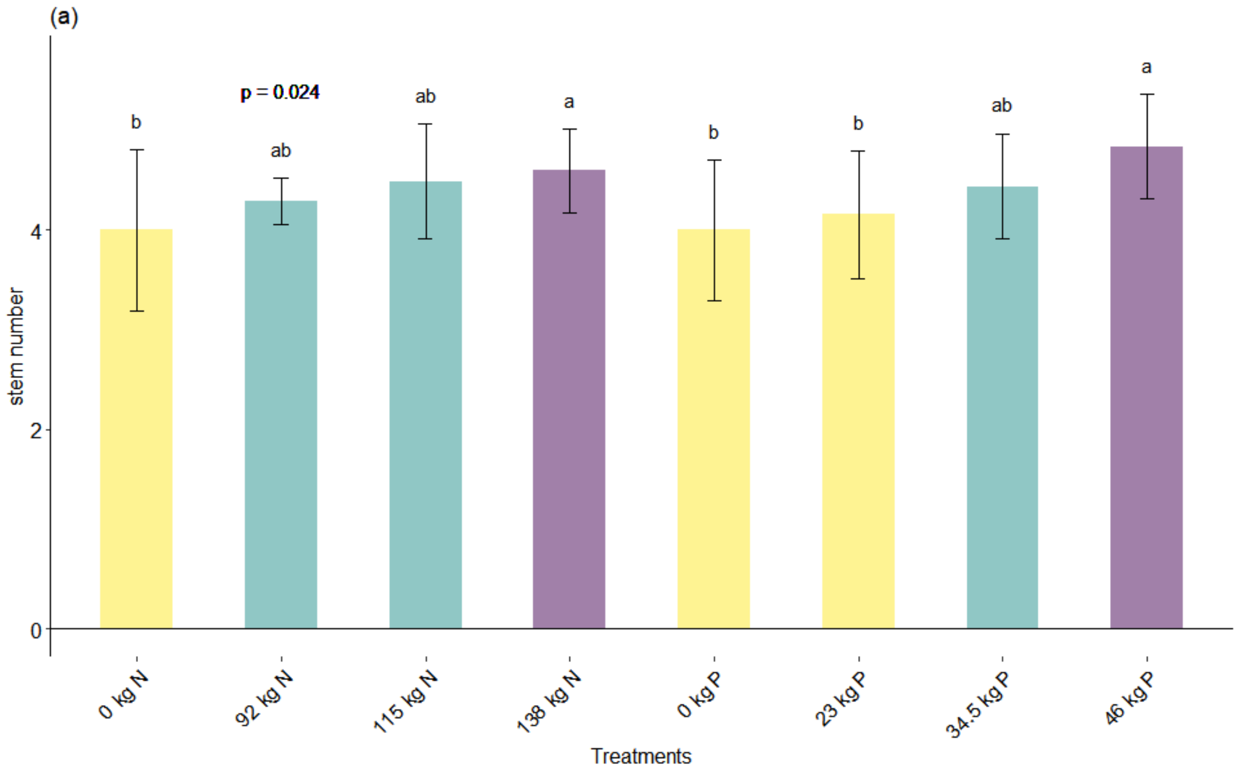

Figure 4: Mean of effect of nitrogen and phosphorus fertilizer rates on stem number of potato

4.3. Effect of Nitrogen and Phosphorus Fertilization on the Yield of Potato

4.3.1. Average tuber number of potato/hills

The average tuber number was highly significantly ($P \leq 0.01$) affected by phosphorus fertilization. Whereas nitrogen and the interactions of nitrogen and phosphorus was not significantly ($P > 0.05$) affected tuber number (Appendix table 2). The highest average tuber number per hill (9.18) was found on the treatment fertilized with 34.5 kg ha^{-1} of phosphorus while the lowest tuber number of 7.2 with the control plot (Figure 5). The increase in the tuber number per hill with an increase of phosphorus fertilization is due to the fact that phosphorus is recognized as a vital nutrient for plant growth, particularly in root development and tuber formation (Yohannes Gelaye et al., 2022). It enhances the plant's ability to utilize other nutrients effectively, which can lead to increased tuber numbers. In addition, phosphorus plays a significant role in energy transfer (ATP), root development, and the synthesis of nucleic acids and proteins, all of which are vital for the initiation and development of tubers. Enhanced phosphorus availability supports the formation of more stolon's and tubers, directly increasing the average number of tubers per hill.

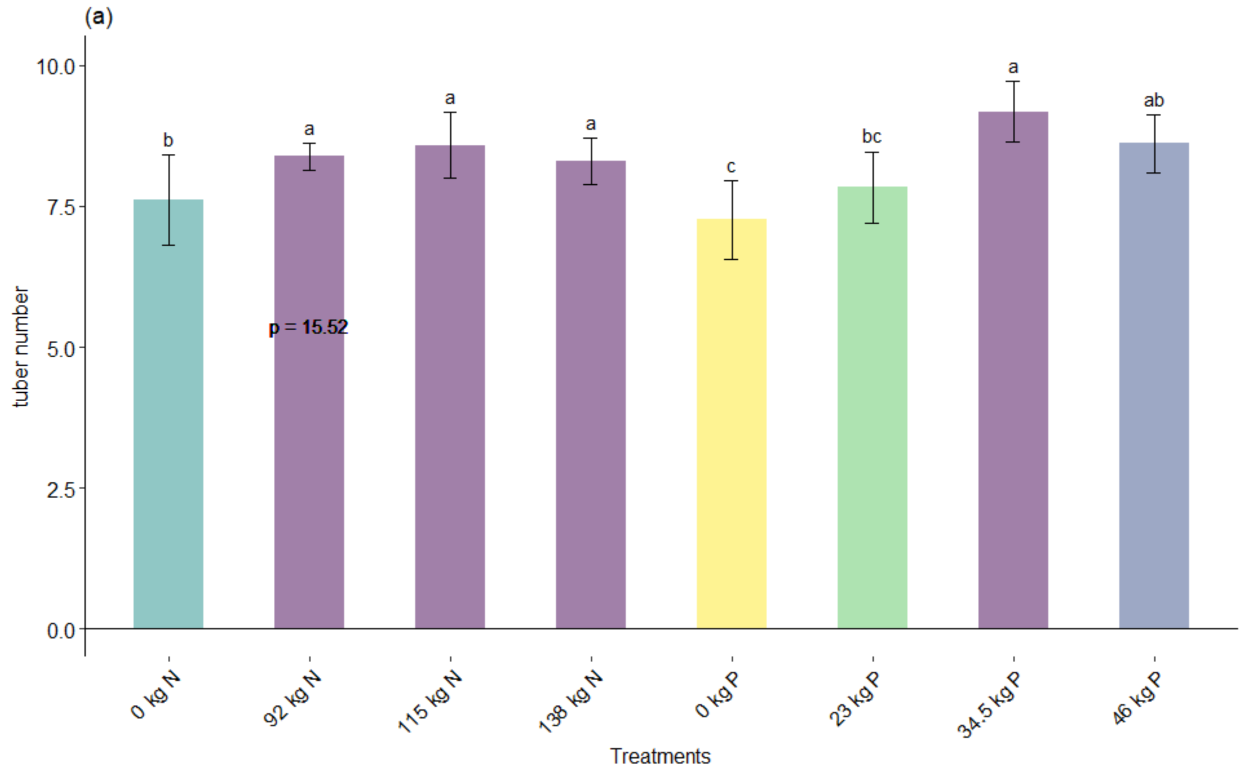

Figure 5: Effect of nitrogen and phosphorus fertilization on the tuber number of potato

Nitrogen is primarily responsible for vegetative growth, including stem and leaf development. It helps maintain photosynthetic activity and extends the duration of active leaves, which can indirectly support tuber bulking and overall yield. In agreement with this finding Nimona Fufa et al. (2024), reported that the tuber number per hill were significantly affected by phosphorus, whereas nitrogen was not significantly affect average tuber number/hill. In addition the study conducted in Masha district demonstrated that phosphorus application influences yield components including tuber number (Isreal Zewide et al., 2012). Another study found that the application of phosphorus significantly increased the average tuber number per hill of potato (Zelalem Ayichew et al., 2009) (Firew Gebremariam et al., 2016). Number of tubers per hill was highly significantly affected by phosphorus rate, but did not respond to nitrogen rate (Desalegn Regassa et al., 2016). On the other hand Israel Zewide et al. (2012), reported that increasing the application of nitrogen significantly increase the tuber number of potato. Nitrogen alone and the combined application with phosphorus does not affect the tuber number of the potato crop.

4.3.2. Average tuber weight

The analysis of variance (ANOVA) revealed that average tuber weight was highly significantly ($P < 0.01$) influenced by nitrogen fertilizer rates, whereas phosphorus and the interaction had no significant ($P>0.05$) effect (Appendix table 2). The maximum tuber weight of 93.97 g was recorded at the plot fertilized by 138 kg ha^{-1} nitrogen (Table 3). The increasing of average tuber weight was consistent with the increasing of nitrogen rate from 0 to 138 kg ha^{-1}. This indicates that nitrogen plays a dominant role in determining tuber size, while phosphorus and its interaction with nitrogen do not contribute substantially to tuber weight variation under the experimental conditions. Nitrogen is a key nutrient for plant growth, photosynthesis, and biomass accumulation, which directly impacts tuber bulking. Higher nitrogen levels likely enhanced leaf area and photosynthetic efficiency, leading to greater carbohydrate allocation to tubers and, consequently, increased tuber weight. However, excessive nitrogen can sometimes promote excessive vegetative growth at the expense of tuber development, but in this study, the tested nitrogen levels (0, 92, 115, 138 kg ha^{-1}) appear to have positively influenced tuber size without reaching detrimental levels. This result was supported by Isreal Zewide et al. (2012) and Gebrie Getie et al. (2022), reported that the increasing of nitrogen significantly increased average tuber weight of potato. Similarly, Wakjira Negero, (2017), discovered that the unfertilized plot had the lowest tuber weight, whereas the plot fertilized with more nitrogen had the highest.

Table 3: Mean of average tuber weight of potato as influenced by nitrogen and phosphorus fertilization

	AvTW (g)
Nitrogen (kg ha^{-1})	
0	77.16^{c}
92	79.64^{bc}
115	88.77^{ab}
138	93.97^{a}
Sign. Level	**
Phosphorus (kg ha^{-1})	
0	86.20
23	88.83

34.5	77.71
46	86.80
Sign. Level	**ns**
CV (%)	**16.35**
Mean	**84.88**

AvTW-Average tuber weight, ns-non-significant, *-significant

4.3.3. Marketable Tuber Yield of Potato

Both nitrogen and phosphorus were very highly significantly ($P \leq 0.001$) and significantly ($P \leq 0.05$) affected the marketable tuber yield of potato respectively, while their interaction effect was non-significant ($P > 0.05$) (Appendix table 2). The highest marketable tuber yield of 35.03 tons per hectare was recorded with a combination of higher nitrogen fertilizer rate of 138 kg ha^{-1} and phosphorus rate of 46 kg ha^{-1} (Figure 4). The two nitrogen levels (115 kg ha^{-1}) and (138 kg ha^{-1}) was not statistically different. While increasing of nitrogen level from 0 to 90 and from 90 to 115 was significantly increases the marketable yield of potato from 24 t ha^{-1} to 32 t ha^{-1}. This increment may be due to nitrogen enhances the development of roots and foliage, which can ultimately improve nutrient and water uptake, as well as overall plant health and directly influences the number and size of tubers produced, thereby positively impacting the marketable yield.

The application of phosphorus also significantly increases the marketable tuber yield. The highest marketable tuber yield (31.57 t ha^{-1}) from the phosphorus level treatments was obtained at the plot fertilized by 46 kg ha^{-1} of phosphorus. However, it was not statistically different with the plot treated by 34 kg ha^{-1} and 23 kg ha^{-1} of phosphorus (Figure 4). The increment of phosphorus level above 23 kg ha^{-1} was not statistically significant. While phosphorus is also important for root development and energy transfer within the plant, its effect may not be as pronounced as that of nitrogen. Inline to this finding Zelalem Ayichew et al. (2009), reported that application of phosphorus up to 60 kg ha^{-1} increased the marketable yield by about 66% over the control.

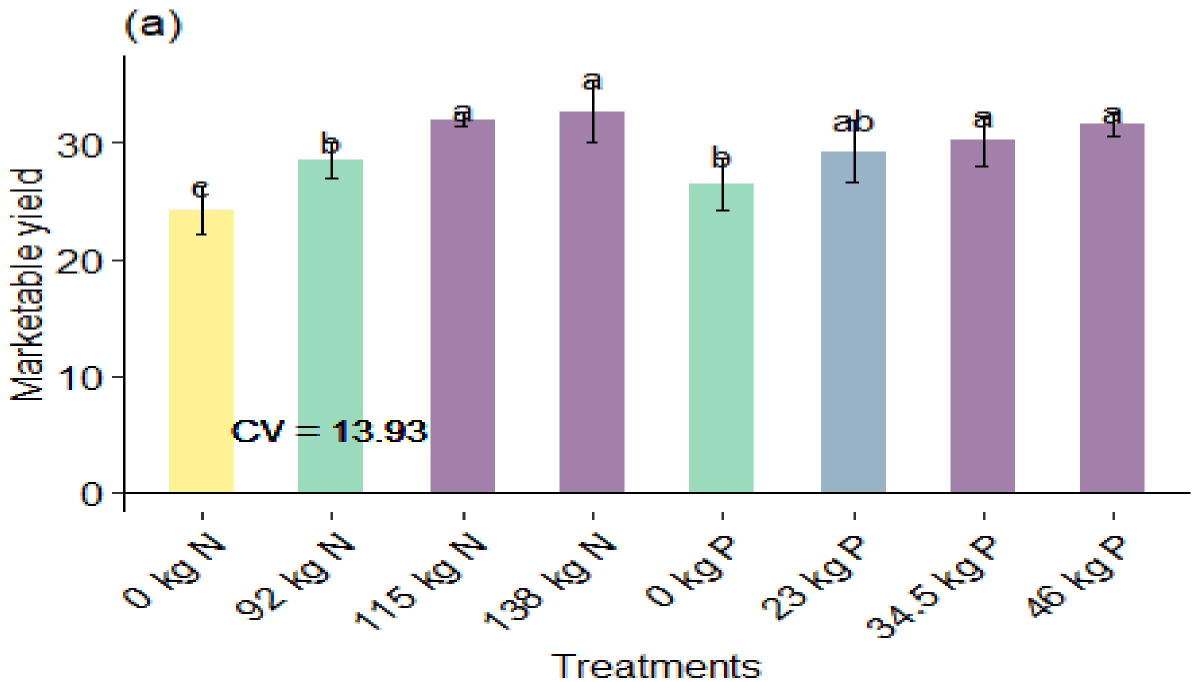

Figure 6. Mean of the effect of nitrogen and phosphorus on the marketable yield of potato

Although phosphorus and nitrogen have significant effects on the marketable tuber yield of potato their interaction did influence significantly this trait. The lack of significant interaction indicates that the effect of nitrogen on marketable tuber yield of potato does not depend on the levels of phosphorus and vice versa. This outcome suggests that while both nutrients significantly improve yield, their interaction does not further enhance the marketable yield beyond what is achieved by applying them independently. In line with this finding Nimona Fufa et al. (2024), reported that marketable yield were significantly influenced by both nitrogen and phosphorus fertilization but the interaction did not affect significantly. Israel Zewide et al. (2012), also reported that, both nutrients play a crucial role in enhancing the yield, with nitrogen showing a particularly strong effect. Similarly the study conducted at Debre Berhan also confirmed that the application of nitrogen and phosphorus significantly increases the marketable yield of potato (Zelalem Ayichew et al., 2009).

4.3.4. Unmarketable Tuber Yield of Potato

Nitrogen and their interaction with phosphorus were significantly (P≤0.05) affected the unmarketable tuber yield of potato; while the effect of phosphorus was not significant (Appendix table 2). The application of 138 kg ha^{-1} of nitrogen brings highest percentage (5.05%) of unmarketable yield (Table 3). This could be the fact that high nitrogen promotes excessive vegetative growth (leafy tops) at the expense of tuber development, leading to misshapen, oversized, or hollow tubers (increasing unmarketable yield).

The combined application of nitrogen and phosphorus was significantly affected the unmarketable tuber yield. The maximum mean percentage (5.69%) of unmarketable yield was recorded at the plot fertilized by the interaction of 138 kg ha^{-1} nitrogen and 46 kg ha^{-1} phosphorus. The lowest unmarketable yield percentage (1.56%) was recorded at the combined application of 0 kg ha^{-1} of nitrogen and 46 kg ha^{-1} of phosphorus (Figure 5). Application of higher phosphorus alone recorded slightly lower unmarketable tuber yield (e.g. 34.5P×0N and 34P×0N), however, when it combined with maximum nitrogen the mean percentage of unmarketable yield becomes exceptionally higher (e.g. 138N×46P and 138N×23P) (Fig. 5). This might be due to high nitrogen can cause hollow hearts or secondary growth (e.g., "chain tubers"). Excessive foliage growth diverts resources away from tuber development, leading to irregular or delayed tuberization. Delayed maturity: prolonged vegetative growth increases exposure to pests/diseases, raising unmarketable yield. Nutrient imbalance: high nitrogen may reduce phosphorus uptake efficiency or disrupt other nutrient ratios, further harming tuber quality. Similar finding was reported by (Workat Sebnie et al., 2021) interaction effect of nitrogen and phosphorus fertilizer application were affect the unmarketable yield of potato significantly at Woleh. In addition, (Birtukan Belachew, 2016) confirmed that, the interaction of nitrogen and phosphorus fertilizers significantly affected the unmarketable yield of potato.

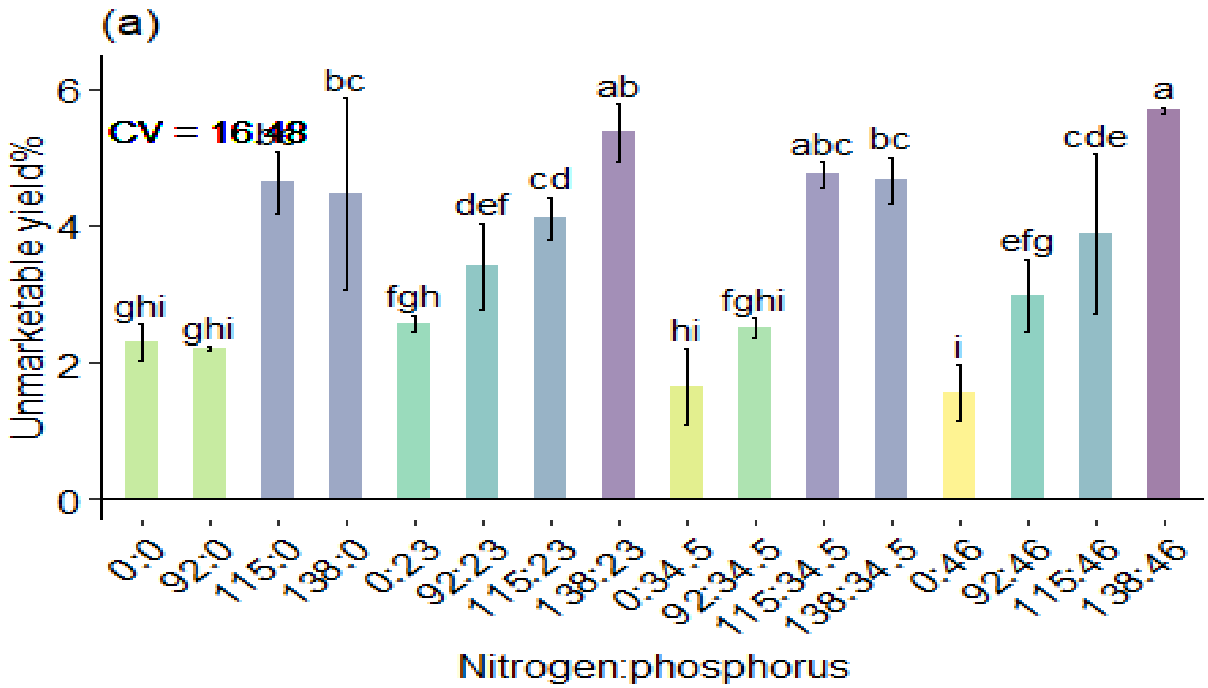

Figure 7. Mean of interaction effect of nitrogen and phosphorus on unmarketable yield of potato

In contrast, phosphorus fertilization did not yield statistically significant differences in unmarketable yield across the treatments, with values remaining consistent around 3.54% regardless of phosphorus application levels. In agreement Zelalem Ayichew et al. (2009), who reported phosphorus did not significantly influence the unmarketable yield. Nimona Fufa et al. (2024), also reported that the interaction of nitrogen and phosphorus was not significant on the unmarketable tuber yield.

4.3.5. Total Tuber Yield of Potato

The total tuber yield has been significantly affected by both nitrogen and phosphorus fertilization. Nitrogen was very highly significantly ($P \leq 0.001$) and phosphorus was significantly ($P \leq 0.05$) affected the total tuber yield of potato; whereas the interaction effect of the two factors was non-significant (Appendix table 2). The plot fertilized with a combination of maximum nitrogen rate (138 kg ha^{-1}) and phosphorus (46 kg ha-1) gave the highest mean tuber yield (36.7 t ha^{-1}), but this did not vary statistically from the plot treated with higher nitrogen alone (Table 4). While the lowest yield (24.11 t ha^{-1}) was obtained from the control (Figure 6). In agreement with this finding Israel Zewide et al. (2012), confirmed that, the increasing of nitrogen fertilization resulted in increased tuber yield. Application of phosphorus at the level of 23 kg ha^{-1} was significantly different with the control plot (Figure 6). The significant increase in total tuber yield as a result of both nitrogen and phosphorus fertilization can be attributed to the crucial roles these nutrients play in potato growth and development. Nitrogen is essential for vegetative growth, particularly leaf and stem development, which directly influences the plant's photosynthetic capacity. An increased leaf area from adequate nitrogen enables more light interception and photosynthate production, which ultimately supports higher tuber formation and bulking (W. Li et al., 2016). Phosphorus, on the other hand, is vital for energy transfer processes (ATP), root development, and early plant establishment (Rosen et al., 2014). It also plays a significant role in enhancing tuber initiation and promoting uniform tuber set. The combined application of nitrogen and phosphorus likely created a more balanced nutrient environment that supported optimal physiological processes throughout the crop cycle.

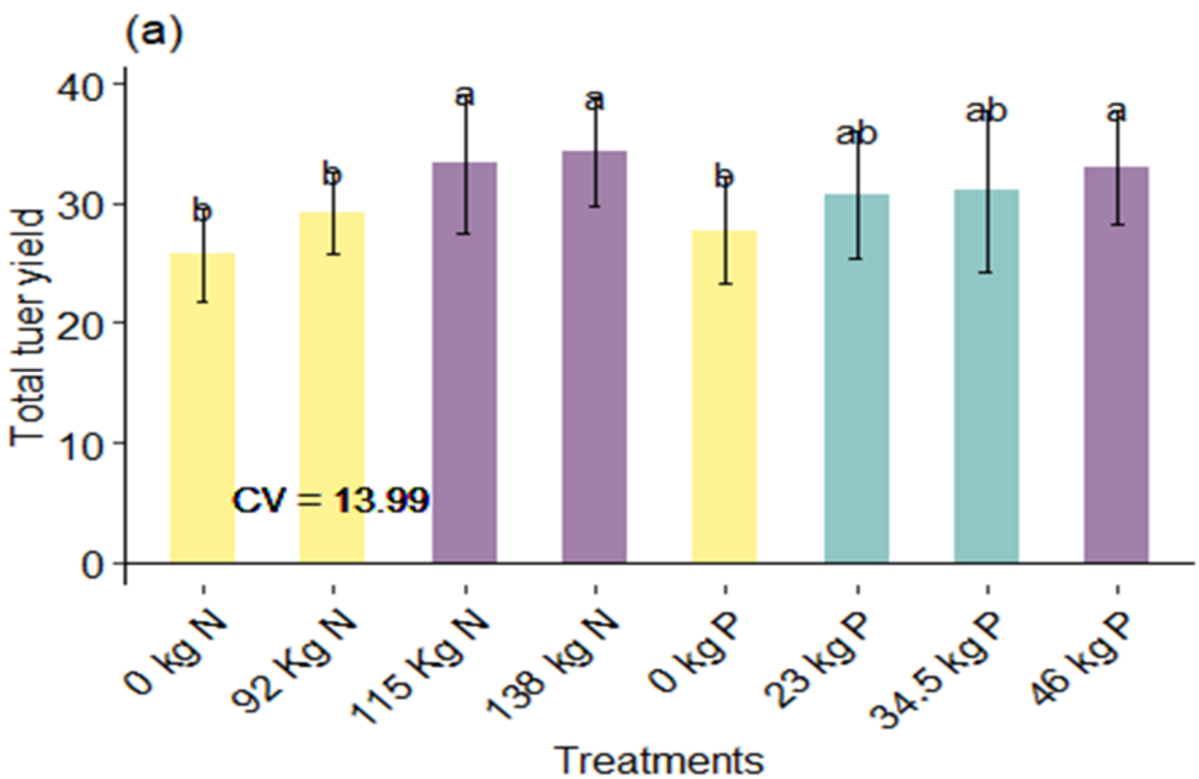

Figure 8. Mean of the effect of nitrogen and phosphorus on total tuber yield of potato

Similar with this finding Nimona Fufa et al. (2024), application of phosphorus significantly increased potato tuber yield up to 72.53% over the unfertilized plot. In addition (Mulubrhan, 2004, Israel Zewide et al., 2012 & Tadele Amare et al., 2022) confirmed increased phosphorus fertilization increases total tuber yield of potato. Application of phosphorus above 23 kg ha^{-1} was not statistically significant.

However, the interaction effect between nitrogen and phosphorus was found to be non-significant, indicating that while both nutrients independently improved total tuber yield, their combined application did not result in any further enhancement beyond the individual effects. Similar findings reported that the interaction of nitrogen and phosphorus did not significantly affect the total tuber yield of potato (Nimona Fufa et al., 2024b). On the other hand Zelalem Ayichew et al. (2009), reported that highest tuber yield was achieved with the combined application of 207 kg ha^{-1} nitrogen and 90 kg ha^{-1} phosphorus and Desalegn Regassa et al. (2016), also reported that, the maximum yield were obtained with the combined application of nitrogen and phosphorus.

4.4. Effect of Nitrogen and Phosphorus Fertilization on the Quality of Potato

4.4.1. Specific Gravity of Potato Tuber

The specific gravity of tuber was highly significantly ($P\leq0.01$) affected by both nitrogen and phosphorus; however, the interaction effect of phosphorus and nitrogen were non-significant (Appendix table 3). The highest specific gravity (1.15) was recorded at 92 kg N ha^{-1} and declines with increasing the nitrogen levels (115 and 138 kg N ha^{-1}), where both showed a specific gravity of 1.12 (Table 4). This may indicate excessive nitrogen could lead to overly vigorous vegetative growth at the cost of tuber quality, possibly diluting the concentration of solids within the tubers. Firew Gebremariam et al. (2016), reported that the application of both nitrogen and phosphorus significantly affected the specific gravity of potato, whereas the interaction was not significant. According to Isreal Zewide et al. (2016), nitrogen and phosphorus application had a highly significant and significant impact on potato tuber specific gravity. However, the interaction effect between nitrogen and phosphorus fertilization was found to be non-significant. This suggests that while nitrogen levels independently influence specific gravity, the combined application of nitrogen and phosphorus does not produce a statistically meaningful effect on this quality parameter. In line to this Zelalem Ayichew et al. (2009), reported that nitrogen treatment significantly reduced the specific gravity and dry matter content of potato.

The highest specific gravity (1.15) is achieved at 46 kg ha^{-1} P_2O_5, indicating that phosphorus enhances tuber density and quality. The increment of specific gravity was consistent with the increasing of phosphorus. The application of 34.5 kg ha^{-1} (1.13) and 23 kg ha^{-1} (1.12) phosphorus was not statistically different with the control plot (1.12) (Table 4). Similarly Firew Gebremariam et al. (2016), confirmed that phosphorus application significantly increased the specific gravity of potato tuber.

Table 4: *Effect of nitrogen and phosphorus fertilization on the specific gravity of potato*

	SG
Nitrogen (kg ha^{-1})	
0	1.13^{ab}
92	1.15^{a}
115	1.12^{b}
138	1.12^{b}
Sign. Level	**
Phosphorus (kg ha^{-1})	
0	1.12^{b}
23	1.12^{b}
34.5	1.13^{b}
46	1.15^{a}
Sign. Level	**
CV (%)	**1.88**
Mean	**1.13**

SG-specific gravity, ns-non-significant, **-highly significant (P=0.01)

4.4.2. Tuber starch content of potato (g/100g)

The tuber starch content was highly significantly ($P<0.001$) affected by phosphorus fertilization and the interaction of nitrogen and phosphorus fertilizer; whereas the main effect of nitrogen was not significant (Appendix table 3). The results indicated a significant enhancement in starch accumulation with optimal phosphorus application rates, where tubers exhibited an average starch content of 0.067g/100g at 46 kg P ha^{-1} compared to 0.016g/100g at the control level (0 kg P ha^{-1}). Conversely, nitrogen fertilization showed a less pronounced effect, with the highest starch content recorded at 138 kg N ha^{-1}, yielding an average of 0.052g/100g (Table 5). In contrary with this finding Parveen et al. (2008), reported that increases in nitrogen levels from 50 to 150 kg ha^{-1} resulted in a substantial rise in starch content. The combined application of nitrogen and phosphorus also highly significantly affected the total starch content. Notably, the interaction between nitrogen and phosphorus treatments revealed that combined applications of 138 kg N ha^{-1} and 34.5 kg P2O5 ha^{-1} resulted in the highest starch concentration of 0.083g/100g, suggesting that balanced fertilization is crucial for optimizing tuber quality in potato production. These findings underscore the importance of nutrient management in enhancing the nutritional profile of potato tubers, which is vital for both consumer health and market value.

Table 5: Mean of interaction effect of nitrogen and phosphorus fertilization on tuber starch content

Treatments		**Parameter**
N	**P**	**TSC g/100g**
0	**0**	0.021^{hi}
92	**0**	0.014^{i}
115	**0**	0.016^{hi}
138	**0**	0.014^{i}
0	**23**	0.03^{gh}
92	**23**	0.05^{de}
115	**23**	0.04^{ef}
138	**23**	0.03^{fg}
0	**34.5**	0.06^{cd}
92	**34.5**	0.05^{ef}
115	**34.5**	0.06^{bcd}

138	**34.5**	0.08[a]
0	**46**	0.07[bc]
92	**46**	0.07[abc]
115	**46**	0.05[de]
138	**46**	0.07[ab]
Sign. Level		***
CV (%)		**16.26**
LSD		**0.01**

TSC=tuber starch content, ***=very highly significant

4.4.2. Dry matter content (DMC)

Phosphorus fertilization was significantly ($P \leq 0.05$) affected the dry matter content of potato. Whereas the effect of nitrogen and the interaction with phosphorus was not significant ($p > 0.05$) (Appendix table 3). Although nitrogen (N) application and its interaction with phosphorus (P) did not significantly affect the tuber dry matter content (%), it does not contradict the general role of nitrogen in promoting plant growth. While nitrogen promotes the accumulation of total dry matter in the plant (including stems, leaves), it does not necessarily increase the concentration of dry matter in the tubers. In fact, higher nitrogen levels often lead to increased water content in tubers, which may dilute the dry matter concentration. Therefore, the lack of significant effect on tuber dry matter content despite nitrogen-enhanced growth is physiologically sound.

The plot fertilized with more phosphorus (46 kg ha^{-1}) had the highest dry matter content (23.43%) (Figure 7). Similar and noticeably lower dry matter content values were shown by the 23 kg ha^{-1} (20.86%) and control (20.85%) plots, suggesting a possible phosphorus deficit that restricts growth and the resulting dry matter content. The observed increases in DMC at higher levels may be explained by the fact that phosphorus is known to be essential for root development and energy transfer in plants. In agreement with this finding Birtukan Belachew (2016), higher levels of phosphorus significantly increases the dry matter content. Firew Gebremariam et al. (2016), reported that, increased the level of phosphorus significantly increased the dry matter percentage of potato tuber, however the increasing of nitrogen beyond 56 kg ha^{-1} highly significantly declines the dry matter content. In contrary with this finding Isreal

Zewide et al. (2016), and Amsalu Nebiyu (2019), reported that the increasing of phosphorus significantly reduced the dry matter content of potato.

Nitrogen was not significantly affected the dry matter content of potato. Similarly, Cucci & Lacolla (2007), also reported that the highest nitrogen decrease the dry matter of potato. On the other hand, Tilahun Alemayehu et al. (2015), revealed that nitrogen significantly reduced the dry matter content of potato. Similarly, increasing nitrogen also highly significantly reduced dry matter content (Isreal Zewide et al., 2016).

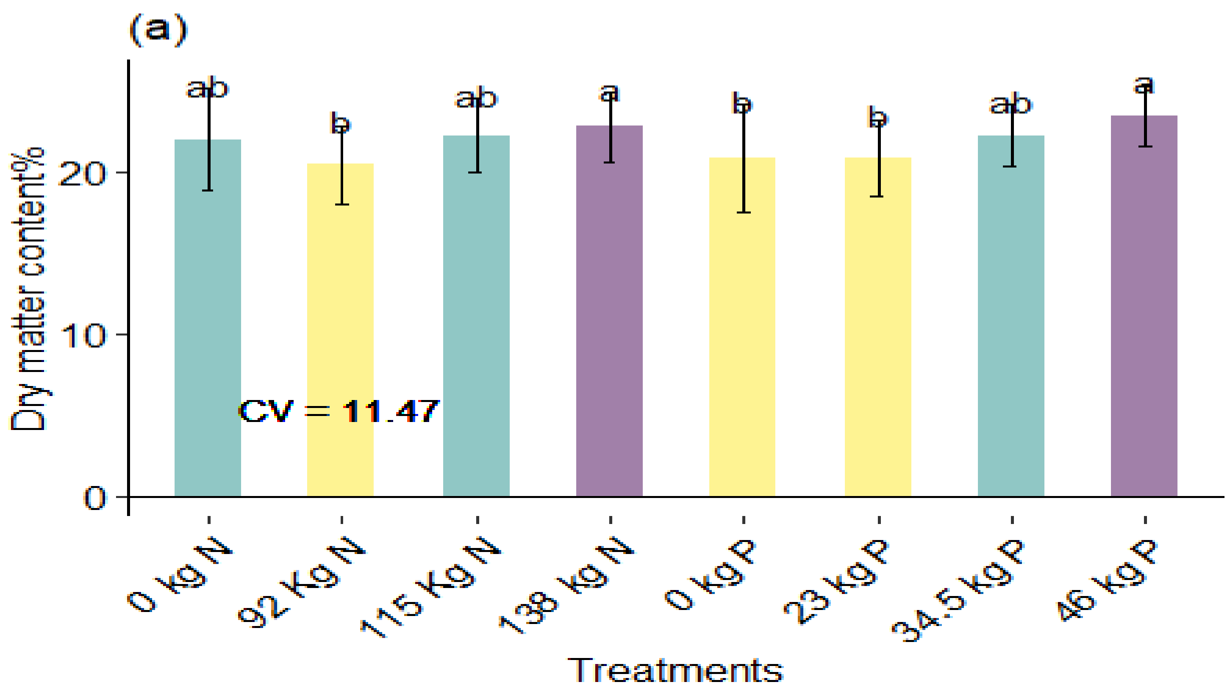

Figure 9. Effect of nitrogen and phosphorus on dry matter content of potato

4.5. Correlation and Regression Analysis

The correlation analysis revealed that total tuber yield exhibited strong positive relationships with key growth and yield parameters in potato (Table 6). It was positively and strongly correlated with plant height (r= 0.73), marketable tuber yield (r=0.98) and it shows the positive and moderate correlation with stem number(r=0.66) suggest that higher vegetative growth supports yield potential, tuber number(r=0.5) and unmarketable tuber yield (r=0.58). Dry matter content (r=0.32), days to emergence (-0.007), specific gravity (r=0.12) and tuber starch content (r=0.41) was the parameters with weaker correlation with total tuber yield. Marketable yield is the predominant component of overall yield, and the nearly perfect correlation with total tuber yield indicates that the majority of produced tubers were probably marketable. The marketable tuber yields also positively correlated with most traits. It was strongly and positively correlated with plant height (r=0.72) and has a moderate correlation with stem number (r=0.66), tuber number (r=0.54) and unmarketable tuber yield (r=0.55). Taller plants typically have greater photosynthetic capacity due to larger leaf areas, leading to more assimilates (carbohydrates) being allocated to tuber growth (P. Li et al., 2020). In addition, more stems per plant generally lead to more stolons, which are the underground structures that develop into tubers. However, it's correlation with days to emergence, dry matter content, specific gravity and tuber starch content was weak.

Table 6: Correlation coefficient result among potato growth, yield and quality parameters at Debark in 2024

Parameters	DE	PH	SN	ATW	TN	MTY	UMTY	TTY	DMC	SG	TSC
DE	1.00										
PH	0.12	1.00									
SN	-0.11	0.50	1.00								
ATW	0.25	0.36	0.06	1.00							
TN	-0.29	0.39	0.60	-0.44	1.00						
MTY	-0.03	0.72	0.66	0.47	0.54	1.00					
UMTY	0.28	0.66	0.28	0.42	0.17	0.55	1.00				
TTY	-0.007	0.73	0.66	0.52	0.50	0.98	0.58	1.00			
DMC	-0.29	0.16	0.46	0.10	0.25	0.32	0.13	0.32	1.00		
SG	-0.32	-0.22	0.04	-0.14	0.04	-0.09	-0.38	-0.12	0.004	1.00	
TSC	-0.07	0.38	0.35	-0.06	0.49	0.41	0.08	0.41	0.23	0.24	1.00

DE=Days to emergence, PH=Plant height, SN=Stem number, TN=Tuber number, MTY=Marketable tuber yield, UMTY=Unmarketable tuber yield, TTY=Total tuber yield, DMC=Dry matter content, SG=Specific gravity, TSC=Tuber starch content, ATW=Average tuber weight.

The regression analysis revealed that nitrogen fertilizer rate could predict marketable potato tuber yield; the mean total tuber yield; unmarketable yield and plant height to the tune of 38% (r^2=0.38); 36% (r^2 =0.36); 63% (r^2=0.63) and 62% (r^2=0.62) respectively (Fig. 8). The equation of the model between marketable tuber yield and nitrogen fertilizer rate was Y=25+0.062X (Fig. 8C), which indicated that for every one unit increase in nitrogen fertilizer rate (kg) there was a corresponding 62 kg potato tuber yield increment and if no nitrogen fertilizer is added the mean marketable potato tuber yield could 25 tons per hectare similarly the equation of the model between plant height and nitrogen fertilizer rate was Y=52+0.11X (Fig 8D) which indicated that for every one unit increase in nitrogen fertilizer rate (kg) there was a corresponding 11cm plant height increment. In contrast, phosphorus levels showed a clear relationship with the measured traits like tuber number, stem number, dry matter content and tuber starch content. As presented on figure 9 the simple linear regression revealed that 19%, 20%, 13% and 74% of the tuber number, stem number, dry matter content and tuber starch content of potato could be predicted by the levels of phosphorus fertilizer, respectively.

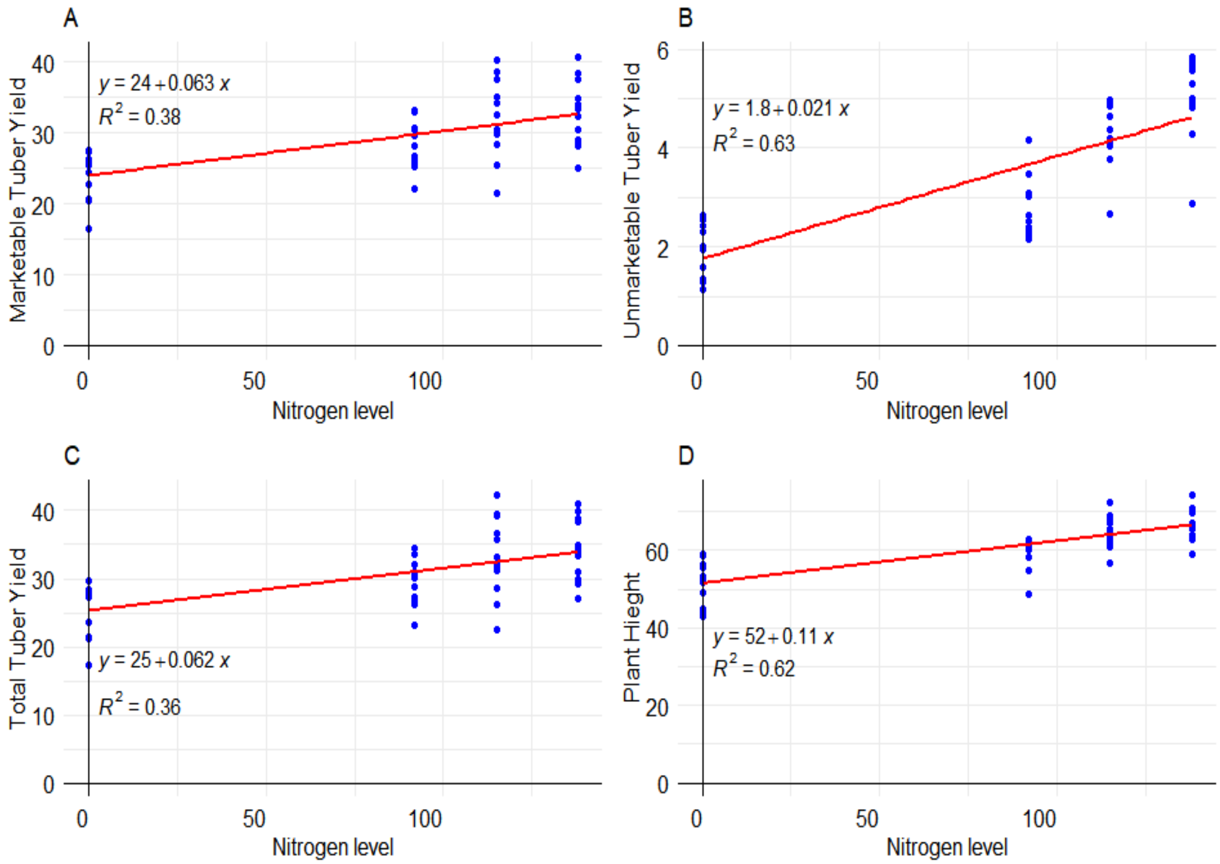

Figure 10: The relationships for nitrogen fertilizer with marketable tuber yield (A); unmarketable tuber yield (B); total tuber yield (C); and plant height (D) of potato at Debark in 2024 irrigation production

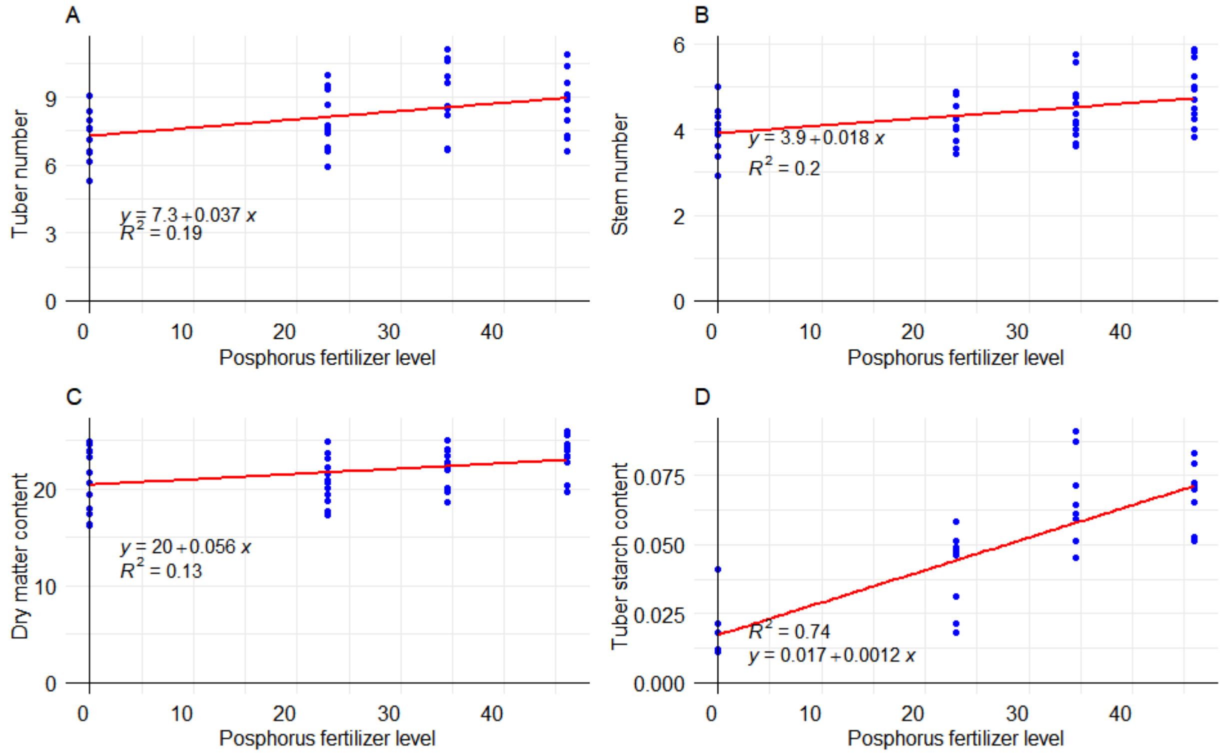

Figure 11: The relationship for phosphorus fertilizer with tuber number (A); Stem number (B); Dry matter content (C) and tuber starch content (D) of potato at Debark in 2024 irrigation production season.

4.5. Partial Budget Analysis Result

In the partial budget analysis of the interaction effect of nitrogen and phosphorus on potato yield, treatments varied in terms of net benefit and marginal rate of return (MRR). While some treatments such as, 115 kg ha^{-1} combined with 46 kg ha^{-1} showed the highest MRR (17132.28%), their net benefits were slightly lower compared to others (Table 8). However, economic recommendations must consider both profitability and the efficiency of investment. A minimum acceptable MRR of 100% was used as the decision threshold, reflecting the return expected by farmers for adopting new practices. Treatments with MRR values below this threshold were excluded from recommendation, even if their net benefits were relatively high, due to the lower incentive for adoption. The partial budget analysis reveals that the treatment combination of 138 kg N ha^{-1} and 46 kg P ha^{-1} generated the highest net benefit of ETB 613173 with a marginal rate of return (MRR) of 152.36% (Table 8). This treatment also produced the highest adjusted marketable yield (31.52 t ha^{-1}), indicating that high nitrogen application combined with mid-range phosphorus fertilization optimizes both productivity and profitability. Other treatments, such as 115 kg N ha^{-1} and 34.5 kg P ha^{-1}, also showed strong performance (net benefit of ETB 602644 and MRR of 8729.78%), but the slightly lower net benefit and higher cost make 138-46 NP the most economically efficient option. In contrast, treatments with no phosphorus (138-0 NP) or excessive nitrogen and lower phosphorus (138-23 NP) resulted in lower net returns or negative marginal returns (marked "D"), suggesting that balanced fertilization is key to maximizing profitability in potato production (Table 7).

Table 7: Dominance analysis for potato marketable tuber yield as influenced by the interaction effect of nitrogen and phosphorus fertilizer at Debark in 2024

NP Rate (treatment combination)	Adjusted Marketable yield (t ha^{-1})	Total variable cost (ETB)	Gross benefit (ETB)	Net benefit	MRR (%)
0,0	20.17	0	403400	403400	
0,23	22.32	2814	446400	443586	1428.07
0,34.5	21.31	4121	426200	422079	D
0,46	23.47	5527	469400	463873	747.77
92,0	23.32	9280	466400	457120	D
92,23	26.60	9774	532000	522226	1373.98
92,34.5	25.11	11636	502200	490564	D
115,0	26.00	11700	520000	508300	D
92,46	27.42	12387	548.400	536013	527
115,23	27.51	13204	550200	536996	120.31
115,34.5	30.83	13956	616600	602644	8729.78
138,0	26.00	14120	520000	505880	D
115,46	31.23	14727	624600	609873	937
138,23	28.83	15624	576600	560976	D
138,34.5	31.40	16276	628000	611724	119
138,46	31.52	17227	630400	613173	152.36

Table 8: Marginal rate of return analysis for potato marketable tuber yield as influenced by the interaction effect of nitrogen and phosphorus fertilizer at Debark in 2024

Nitrogen and phosphorus rate (treatment combination)	Total variable cost (ETB)	Net benefit (ETB)	MRR (%)	Rank
0,0	0	403400		10
0,23	2814	443586	1428.07	2
0,46	5527	463873	747.77	5
92,23	9774	522226	1373.98	3
92,46	12387	536013	527.63	6
115,23	13204	536996	120.31	8
115,34.5	13956	602644	8729.78	1
115,46	14727	609873	937	4
138,34.5	16276	611724	119	9
138,46	17227	613173	152.36	7

MRR-marginal rate of return, cost of urea=44.40ETB/Kg, cost of NPS=43.20ETB/Kg, farm get price of potato=20ETB/Kg

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The application of nitrogen and phosphorus significantly influenced the growth, maturity period, and quality parameters of the potato crop. Nitrogen played a critical role in enhancing vegetative growth and increasing yield, while phosphorus contributed to improved yield, dry matter content and physiological maturity. Their combined application resulted in extended days to maturity and enhanced tuber starch accumulation, representing the importance of balanced nutrient management. The attained total tuber yield (34.2 t ha^{-1}) under the highest nitrogen (138 kg ha^{-1}) treatment exceeded the national average yield by more than double, clearly showing the production potential of the crop under improved fertility management. Furthermore, the highest net benefit (613173 ETB) and acceptable marginal rate of return (152.2%) were achieved at the maximum (138 kg ha^{-1} N and 46 kg ha^{-1} P) levels, underscoring economic advantages and profitability.

Despite these positive responses, the regression analysis revealed a linear trend in yield increase with rising nitrogen and phosphorus levels, indicating that the crop's nutrient demands were not fully met within the tested range. This suggests that the applied NP rates were sub-optimal, and higher rates may be required to reach the biological yield potential and economic threshold.

5.2. Recommendations

Based on the result of the current study the application of 138 kg ha^{-1} of nitrogen combined with 46 kg ha^{-1} phosphorus can be recommended to profitable production of the potato crop for Debark and similar agro-ecology. However, for resource limited farmers, the combined application of 115 kg N ha^{-1} and 34.5 kg P ha^{-1} presents a viable alternative, offering a slightly lower net benefit of 602644 ETB but an exceptionally high MRR of 8729.78%, indicating efficient returns on minimal investments. Therefore, it can be recommended for those with tight budget constraints, as it delivers outstanding returns per unit of capital invested. For quality centric fertilization strategies application of 46 kg ha^{-1} of phosphorus should be emphasized to sustain tuber quality, and application of nitrogen beyond 138kg ha-1 may lead to excessive vegetative growth at the expense of tuber quality.

Since the study was conducted by a single season and location it needs to repeat at different locations and seasons in the district is recommended. In addition, the regression analysis revealed a linear increasing trend on the yield with rising nutrient levels, indicating the need to repeat the study using expanded rates and levels of nitrogen and phosphorus to better capture the yield response curve.

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APPENDIXS

Appendix table 1. Mean square values for growth parameters

Source of variation	Degree of freedom	Days to emergence	Plant height	Stem number
Nitrogen	3	4.24^{ns}	549.9**	1.83*
Phosphorus	3	7.41^{ns}	76.9*	4.29**
N*P	9	8.79*	11.3^{ns}	0.021^{ns}
Replication	2	5.13	9.1	0.075
Residuals	30	3.08	19.0	0.35
CV%		7.88	7.14	13.19

Appendix table 2. Mean square values for yield parameters

Source of variation	Degree of freedom	Tuber number	AvTW	MTY	UMTY	TTY
Nitrogen	3	2.12^{ns}	1621.6**	182.25***	23.31***	187.85***
Phosphorus	3	8.59**	48.7^{ns}	55.97*	0.59^{ns}	56.43*
N*P	9	1.07^{ns}	118.9^{ns}	4.92^{ns}	0.83*	6.52^{ns}
Replication	2	3.53	18.2	52.70	0.01	50.39
Residuals	30	1.67	192.8	16.87	0.35	18.29
CV%		15.72	15.84	13.99	16.48	13.96

MTY-marketable tuber number, AvTW-average tuber weight, UMTY-unmarketable tuber yield, TTY-total tuber yield, CV-coefficient of variation

Appendix table 3. Mean square values for quality parameters

Source of variation	Degree of freedom	SG	DMC	TSC
Nitrogen	3	0.0025**	12.06^{ns}	0.00006^{ns}
Phosphorus	3	0.0021**	18.69*	0.00014^{ns}
N*P	9	0.0005^{ns}	3.10^{ns}	0.01922***
Replication	2	0.0005	12.71	0.00011
Residuals	30	0.0004	5.73	0.00015
CV%		1.88	11.47	16.26

SG-specific gravity, DMC-dry matter content, TSC-total starch content, CV-coefficient of variation

Appendix 4: Experimental field at the time of planting and at full emergence

 

Appendix 5. The field performance of the control and 115 kg $^{-1}$ x 34.5 kg ha^{-1} NP fertilized plot

Appendix 6. The pictures in the laboratory (dried tubers in an oven dry)

AUTHOR'S BIOGRAPHY

The author Akalu Mihretie Tsigie was born on April 1, 1998, at Debark, north Gondar zone. He completed his primary education (Grade 1–8) at Wuraba elementary school and his secondary education (Grade 9–12) at Debark secondary and preparatory school. He earned a Bachelor of Science (BSc) in Horticulture from Debark University in 2021 and is currently pursuing a Master of Science (MSc) in Horticulture at Bahir Dar University. Since July 2021, he has been employed as a Graduate Assistant at Debark University, where he contributes to teaching, research, and mentorship in horticultural sciences.