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Response of Potato (*Solanum tuberosum L.)* to Nitrogen and Phosphorus Fertilizers in Asagirt District of North Shewa, Ethiopia

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Abstract

Potato is a vital crop in Ethiopia's middle- and high-altitude regions, particularly in the North Shewa highlands, where it is the primary *Belg* (short rainy season) crop after barley. However, production is hindered by low soil fertility, erosion, nutrient depletion, poor crop management, and suboptimal fertilizer application. An on-farm experiment was carried out to evaluate potato performance under various levels of nitrogen and phosphorus fertilizer in the 2020 and 2021 *Belg* planting seasons on four farm fields in Asagirt District, North Shewa Zone, Ethiopia. A factorial experiment comprising four amounts of N (23, 46, 69, and 92 kg N ha $^{-1}$) and three amounts of P (23, 46, and 69 kg P_2O_5 ha $^{-1}$), along with a control treatment (0, 0) N and P_2O_5, was carried out via a randomized complete block design (RCBD) involving three replicates. Tuber yield, growth, and soil data were measured and subsequently analyzed using Statistical Analysis System software. The results revealed a substantial ($p<0.001$) effect of N fertilizer on key tuber yield and growth parameters. In contrast, P rates and their interaction with N did not affect most parameters. The highest marketable tuber production of 25.50 tons ha^{-1} was attained from a nitrogen rate of 92 kg N ha^{-1}. For phosphorus, the highest yield (22.71 tons ha^{-1}) was achieved with 69 kg P_2O_5 ha^{-1}, whereas the no input treatment yielded the lowest (18.68 tons ha^{-1}). According to the economic analysis, the greatest marketable yield (26.52 t ha^{-1}) and the highest benefit-cost ratio (2.67) were achieved with an application of 92 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}. Therefore, this fertilizer combination is recommended as the optimal rate for potato production in Asagirt and similar agroecology during the *Belg* season until further N and P rates are determined through multilocation studies.

Keywords: Belg season, Fertilizer application, Marketable yield, Potato, Soil fertility.

Introduction

Potato (*Solanum tuberosum L.*) is a prominent agricultural commodity, recognized as a major non-cereal food crop (Rivelli and Mari, 2018) and the most consumed vegetable, placing it fourth in importance, behind maize, wheat, and rice (Devaux et al., 2014; FAO, 2018). For the same area of land and growing time, it yields more dry matter, protein, and energy than cereals (Rajiv and Kawar, 2016; Singh et al., 2023). It is an excellent source of essential nutrients, with a balanced profile of amino acids, vitamins (C, B6, B1, folate), and minerals like potassium, phosphorus, and magnesium (Lal et al., 2020). Additionally, when eaten with the skin, it provides high dietary fiber and is rich in antioxidants like polyphenols, vitamin C, carotenoids, and tocopherol (Egata Shunka, 2018; Warsewicz et al., 2021). In Eastern and Central Africa, potato represents an important nutritional and market crop, substantially contributing to national food availability, nutrition, and livelihoods, while reducing financial insecurity and supporting the full agri-food value chain (Abebe Chindi, 2019).

Potato is a principal crop cultivated in Ethiopia’s mid and highland zones, with nearly 70% of cropland considered suitable for farming (Desta Bekele, 2024). This species was introduced to Ethiopia through the efforts of German botanist Shimper in 1858 (Berga Lemaga et al., 1994). Potatoes have become a significant source of food and income for small-scale growers. In Ethiopia, it ranks as the third most cultivated and consumed root and tuber crop, following sweet potato and taro ('godere') (CSA, 2021). It produces 1.14 million tons of tubers annually on approximately 85,988.43 hectares. However, the average yield at the national (13.28 ton ha^{-1}) and regional (13.59 ton ha^{-1}) levels remains low (CSA, 2021) compared with the global average of 20 ton ha^{-1} (CIP, 2018). This may be resulting from challenges like inadequate soil fertility, insufficient fertilizer use, poor-quality seed availability, and damage from pests and diseases (Bacha Tamiru et al., 2023; Workat Sebnie et al., 2021).

The two main nutrients limiting Ethiopia's crop production are nitrogen and phosphorus (Beamlaku Alemayehu et al., 2023; Sofonyas Dargie et al., 2022; Tadele Amare et al., 2022a). In a recent study, Erkihun Alemu et al. (2024) identified nitrogen and phosphorus as the main nutrient constraints on potato production in Ethiopia's Amhara Region. These essential macronutrients are required in significant amounts and are widely applied to most annual crops (Hawkesford et al., 2023). Various studies conducted on Ethiopian soils have demonstrated that the application of N and P fertilizers is positively correlated with higher potato yields (Desalegn Regassa et al., 2016; Tadele Amare et al., 2022b; Workat Sebnie et al., 2021). Nevertheless, the trials were done only over the main rainy period, in different agroecological zones and soil types. Therefore, the literature lacks location-specific nutrient recommendations, highlighting the need for site-specific fertilizer recommendations in this area.

The soils of the Ethiopian highlands, including the Asagirt district (MOA and ATA, 2016), are notably deficient in nitrogen and phosphorus (Beza Shewangizaw et al., 2024; Hillette Hailu et al., 2015). This nutrient limitation necessitates a supplement of N and P nutrients to increase crop

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productivity. Additionally, potato is a major *Belg* season crop next to barley in Ethiopia, especially in the Asagirt district, which receives a bimodal rainfall pattern. Despite this potential, the productivity of the crop in Ethiopia, as well as in Asagirt, is generally small in comparison with the true potential of this crop (Amha Besufkad et al., 2019). The major problem resulting in lower yields was ineffective management, including a lack of site-specific fertilizer rate recommendations. In addition, there were no other findings or studies on potatoes in Asagirt in *Belg* or during the main rainy season. This highlights the urgent need for studies to establish site-specific nitrogen and phosphorus fertilizer recommendations for potatoes. This field experiment aimed to evaluate the most effective N and P fertilizer levels for potato growth and productivity in Asagirt District, North Shewa Zone, Amhara Region.

Materials and methods

Experimental site description

This research was executed over two continuous *Belg* seasons, 2020 and 2021, at four experimental sites in Gola Kebele, a major potato production area in the Asagirt District, part of the North Shewa Zone, Ethiopia (Figure 1). The *Belg* season occurs annually from March 26 to June 25 according to the Ethiopian calendar (Mulualem Abera et al., 2023). This period is critical for the growth of various crops in Ethiopia's highlands, which have bimodal rainfall patterns. Geographically, the experimental site is located between 9°22'07.9" and 9°21'35.4"N latitude and 39°33'29.5" and 39°33'53.9"E longitude, situated at 3,062-3,096 masl. The ten-year average temperature in Asagirt ranges between 9.33°C and 19.17°C. The experimental site exhibits a double rainy season pattern, having an average annual precipitation of 924.83 mm (Ankober meteorological station). The soil at the trial site is a Cambisol, which is often found in areas with moderate to heavy rainfall. Cambisols are well-drained soils, making them suitable for agricultural practices (Alemayehu Regassa et al., 2023). Locally, this soil is referred to as "*Lem afer*," a term that reflects traditional knowledge and regional soil classifications. The predominant soil type in the Asagirt highlands is Cambisol, which supports plant growth and increases agricultural yields.

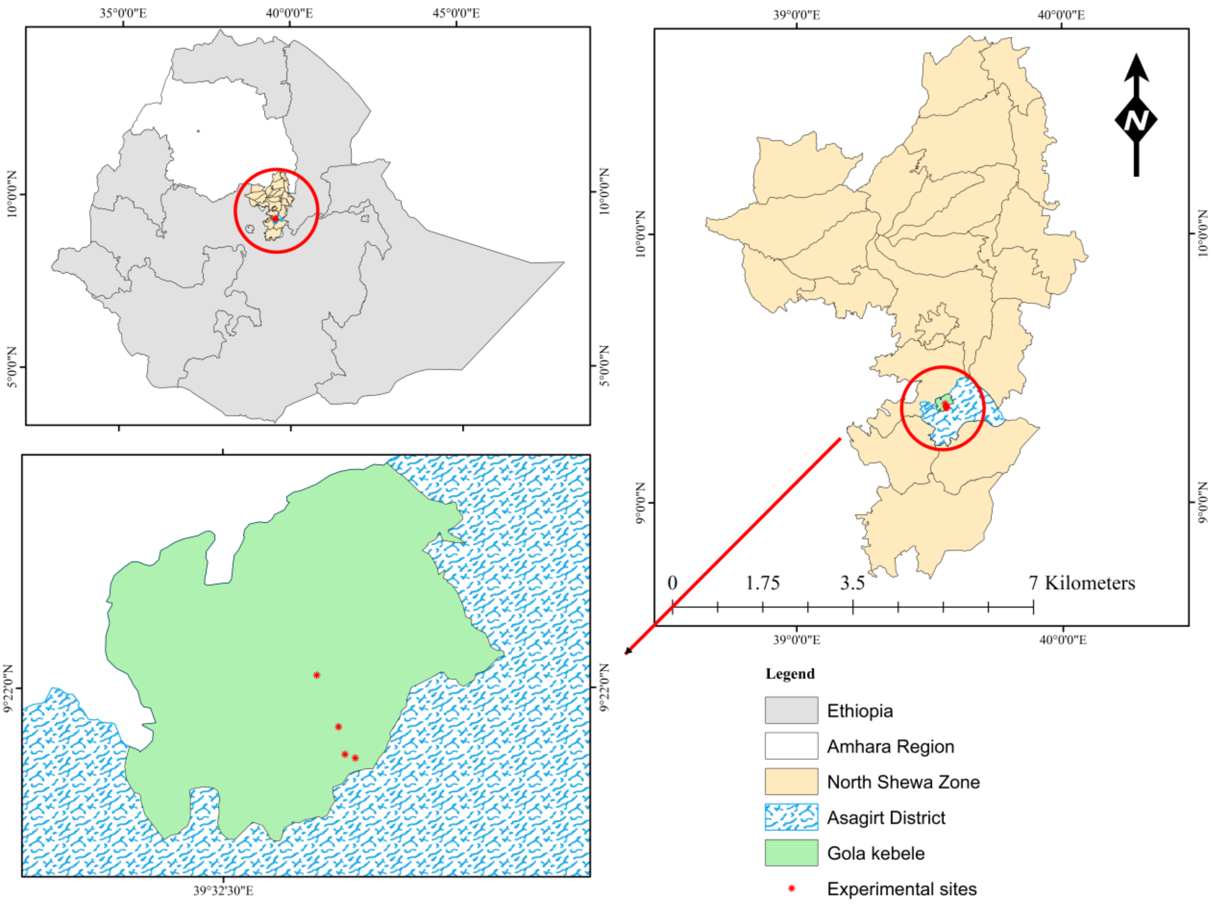

Figure 1**.** Map showing the study area location.

Rainfall distribution during the cropping season

Asagirt, a district within the Ethiopian highlands, is characterized by two distinct rainfall periods: the primary rainfall period, spanning June to September, and the Belg rainfall period (March 26 to June 25). This experiment was conducted under *Belg* conditions. Rainfall data was obtained directly by installing a rainfall gauge for two consecutive Belg seasons. The rainfall distribution is greater in the first rainfall period than in the second (Figure 2), which influences the marketable yield of potatoes, resulting in higher yields in the first and lower yields in the latter year.

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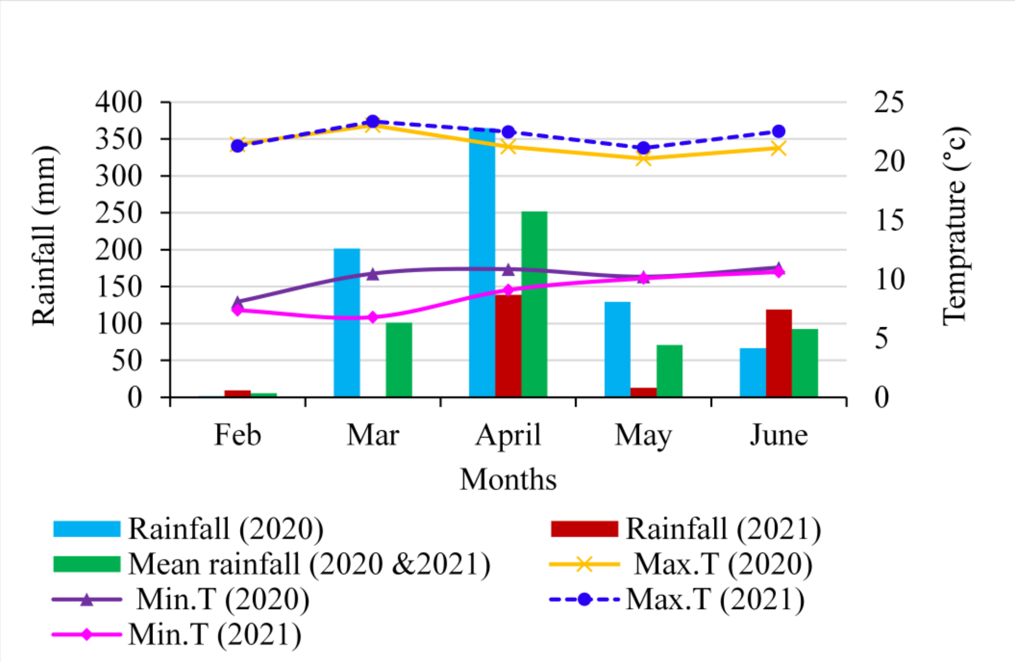

Figure 2. Rainfall distribution and temperature trends for two consecutive *Belg* seasons (years).

Experimental design and treatments

Several experiments in Ethiopia have shown that the addition of both N and P is mandatory for soils in Ethiopian highlands, with nitrogen being the primary yield-limiting nutrient, followed by phosphorus (Beamlaku Alemayehu et al., 2023; Erkihun Alemu et al., 2024; Sofonyas Dargie et al., 2022; Tadele Amare et al., 2022a; Yalemegena Gete et al., 2025). Therefore, this experiment included four N (23, 46, 69, and 92 kg ha $^{-1}$) and three P (23, 46, and 69 kg ha $^{-1}$ P_2O_5) levels and one (0, 0) NP satellite or pilot treatment combined in a factorial arrangement. The experimental plots were laid out in the field as an RCBD, with every treatment repeated across blocks three times. A total of 39 plots (13 treatments × 3 replications) were established, each measuring 3.75 m × 1.5 m (5.625 m²). Within each plot, plants were arranged in five plants per ridge, with 30 cm spacing between plants and 75 cm between ridges. Plots were spaced 1 m apart, with 1.5 m between blocks.

Soil sample analysis

Within each experimental site, four pre-planting soils were sampled from ten locations at a soil layer ranging from 0 to 20 cm, walking in a zigzag fashion with an auger. These samples were then combined into a composite sample. The pre-planting soil samples were analyzed to determine total nitrogen, available phosphorus, pH (at a 1:2.5 soil-to-water ratio), organic carbon, and soil texture. The Kjeldahl procedure was employed to determine total nitrogen (Jackson, 2005), while the Bray II method was used to quantify available phosphorus (Bray and Kurtz, 1945). A soil-water mixture at a

1 to 2.5 ratio served as an analytical medium for the electrometric determination of soil pH. The soil OC (%) amount was quantified via the Walkley and Black procedure (Jackson, 2005), and soil texture was determined via the Bouyoucos hydrometer technique (Huluka and Miller, 2014).

Experimental materials and procedures

The 'Gudenie' potato variety was used for the study. Released in 2006, it has a production capacity of 21 ton ha^{-1} on farmers' fields and 29.17 ton ha^{-1} under research conditions, with a plant height exceeding 60 cm. Urea and TSP, with nutrient compositions of 46-0-0 and 0-46-0, respectively, served as the sources of nitrogen and phosphorus. The full phosphorus amount was applied during planting, while nitrogen was split into three applications: one-third was utilized at sowing, the second third was added approximately 45 days later, and the last third at the beginning of tuber development (early flowering stage). The trial was executed at four experimental sites during the *Belg* season for two consecutive years. The experimental plots were plowed three times with oxen prior to planting. The field was properly laid out and prepared to ensure optimal conditions for crop establishment. All necessary management practices, including pest and disease control, as well as weeding (first and second weeding) and hoeing, were carried out according to the standard recommendations for potato cultivation. Weeding and hoeing were performed manually.

During the first year of the experiment, the crop was affected by cutworm infestation and early blight disease. For the cutworm, we utilized dimethoate, whereas for early blight, we utilized the chemical rodomel gold at the rates and schedules recommended by the manufacturer, and it was effective. Like in the first year, the cutworms were also observed during the second year of the experiment. To address this, we applied dimethoate at the rates and schedules recommended by the manufacturer, which proved effective. To minimize border effects, the yield was estimated at harvest using tubers from only the middle three ridges of each plot.

Data collection

Plant height was recorded in centimeters at physiological maturity by randomly sampling ten plants located in the middle ridge of each experimental unit. The tubers were categorized as marketable or unmarketable on the basis of size and condition. Tubers weighing more than 25 g and free from damage or blemishes were classified as marketable. After harvesting, tubers from the net plot were sorted into two categories. Marketable yield consisted of healthy tubers weighing over 25 g, while unmarketable yield included unhealthy or undersized (< 25 g) tubers. The total tuber yield was calculated by summing the weights of the two categories, and the total potato number was determined by summing their respective counts.

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Statistical analysis

Data went through the analysis of variance (ANOVA) using SAS (v. 9.1.3), with mean separation performed by the Duncan multiple range test (DMRT). Correlation analysis, following (Gomez and Gomez, 1984), was also conducted in R Studio to assess relationships between variables.

Economic analysis

This study included an economic assessment to evaluate the profitability of applying nitrogen, phosphorus, and mixtures of these nutrients in potato production across the research sites, using the approach outlined by Mishan and Quah (2020). The aggregate production costs and sale prices of potatoes were collected for economic analysis. The economic analysis compared various N and P_2O_5 treatment combinations for gross benefit, total costs, and net income.

Results and discussion

Soil analysis findings for the trial sites

The initial physicochemical characteristics of the soil at the trial location are given in Table 1. Soil at the trial site was somewhat acidic, exhibiting a pH range of 5.25 to 5.91 (average 5.57), based on the ratings by Tekalign Tadesse et al. (1991). This outcome could be because the experimental site receives moderate to high levels of rainfall and is situated at a relatively high altitude variation of 3062–3096 m.a.s.l. The overall nitrogen content at the experimental site had a mean value of 0.18%, which was considered low based on the rating by Landon (2014). This implies that due to the limited availability of total nitrogen at the research location, optimum potato yields could not be expected without the use of N fertilizers. Similarly, the experimental site's mean organic carbon content (2.27%) was rated as low according to the ratings of Landon (2014). According to Cottenie (1981), soil analysis at an experimental site revealed that available phosphorus levels ranged between 9.41 and 16.96 mg kg^{-1}, classifying the soil within the medium category, with a mean value of 13.83 mg kg^{-1}. This might be the cause of the lack of a discernible yield difference in this experiment at phosphorus rates greater than 23 kg P_2O_5 ha^{-1}. The study sites' soil particle-size distribution included clay, clay loam, silty clay, and clay loam. Clay soils are characterized by fine particles, which result in low permeability and high nutrient retention (Kumari and Mohan, 2021). The presence of clay loam and silty clay suggests a mixture of fine- and medium-sized particles, offering a balance between drainage and nutrient-holding capacity, which is important for the crops in the study (Phogat et al., 2015).

Table 1. Soil conditions at the experimental site before planting

Parameters	2020		2021		Mean	Rating range	Ratings	Source
	Site1	Site2	Site3	Site4				
pH (1:2.5)	5.66	5.91	5.45	5.25	5.57	5.3-5.9	Moderately acidic	Tekalign Tadesse et al. (1991)
TN (%)	0.20	0.17	0.16	0.18	0.18	0.1-0.2	Low	Landon (2014)
OC (%)	2.97	2.49	2.08	2.32	2.27	2.0-4.0	Low	Landon (2014)
Av.P (mg kg $^{-1}$)	9.41	16.96	14.57	14.36	13.83	10.0-17.0	Medium	(Cottenie, 1981)
Sand (%)	22	32	16	20				
Silt (%)	36	38	40	38				
Clay (%)	42	30	44	42				
Textural class	Clay	Clay loam	Silty clay	Clay				

Note: pH = power of hydrogen, TN = total nitrogen, OC = organic carbon, Av. P = available phosphorus

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Plant height

The performance of potato is presented in Figure 3 and Figure 4. The findings of these studies revealed that there was growth and yield variability across seasons (Table 2). Potato yield is strongly impacted by the greater rainfall distribution during the first growth season than in the second, which results in higher yields in the primary *Belg* season and reduced yields in the second (Table 4). The results of the analysis of variance indicated that nitrogen significantly impacted plant height ($P < 0.01$), whereas phosphorus alone and its interaction with nitrogen did not impact potato height (Table 2).

Figure 3. Field performance of potato during the start of flowering at Asagirt district site 2.

Table 2. Analysis of variance (ANOVA) for the effects of year, location, nitrogen, phosphorus, and their interactions on potato growth and yield parameters.

Source of variation	Df	Values of the mean square				
		Plant height	Marketable tuber number	Total tuber number	Marketable tuber yield	Total tuber yield
Year	1	18516***	12063***	1320 ^{ns}	12944***	13061***
Loc	3	1808***	8157***	30047***	1918***	1982***
Rep	2	34	1924***	1280^{ns}	454***	445***
N	3	289***	2487***	2624***	219 ***	225 ***
P	2	7^{ns}	206^{ns}	761^{ns}	4^{ns}	5^{ns}
N*P	6	8^{ns}	450^{ns}	578^{ns}	26^{ns}	27^{ns}
Error	127	19	214	417	29	30
Total	143					
R Square		0.90	0.61	0.59	0.83	0.83
Cv (%)		10.1	16.4	18.8	24.0	23.7

Note: Df = degree of freedom, *** = highly significant ($p < 0.001$); ns = non-significant $p \geq 0.05$

In this trial, both the yearly and combined analyses showed that the 92 kg N ha^{-1} fertilizer rate produced the tallest plants, while the control group had the shortest (Table 3). The substantial increases in plant height with increasing nitrogen addition are owing to the essential function of nitrogen in stimulating vegetative growth by supporting cell division, elongation, and photosynthesis via its effects on chlorophyll, proteins, and nucleic acids (Leghari et al., 2016). Likewise, several experiments have demonstrated that plant height increases significantly in response to increases in nitrogen levels (Fayera Wakjira, 2017; Kurka and Shumbulo, 2022; Tadele Amare et al., 2022b; Zhang et al., 2024). These authors reported that increasing nitrogen fertilizer rates positively influences potato plant height, with higher N levels leading to taller plants. Similarly, Solomon Fantaw et al. (2019) noted that a rise in nitrogen application spanning 0 to 110 kg ha^{-1} enhanced potato height from 56.07-64.4 cm. In line with the findings of this experiment in India, Yadav et al. (2022) observed a significant increase in plant height in response to higher nitrogen rates.

The P_2O_5 rate did not significantly influence plant height ($p \geq 0.05$). This lack of significance could be due to the medium level of available phosphorus in the soil (Table 1). Consistent with these findings, previous studies by Niguse Abebe (2016), who reported 3.83 ppm of available P in the study soil, and Workat Sebnie et al. (2021), who reported soil available P levels ranging from 15.45 to 18.04 ppm, reported that different amounts of phosphorus fertilizer didn't make a significant difference in the final height of the potato plants.

Table 3. Effects of N and P_2O_5 fertilizer rates on potato growth and yield in the Asagirt district of North Shewa, Ethiopia.

N or P Rates	Plant height (cm)			Marketable tuber number (plot)			Total tuber number (plot)		
	2020	2021	Average	2020	2021	Average	2020	2021	Average
N kg ha^{-1}									
23	51.2^{c}	29.1^{b}	40.2^{c}	89.2^{c}	77.8	83.5^{c}	100.2^{c}	103.4	101.8^{b}
46	51.9^{c}	32.1^{a}	42.0^{c}	88.1^{c}	76.1	82.1^{c}	102.6^{bc}	104.1	103.3^{b}
69	55.7^{b}	32.9^{a}	44.3^{b}	100.5^{b}	80.9	90.7^{b}	113.8^{b}	105.4	109.6^{b}
92	59.7^{a}	33.7^{a}	46.7^{a}	115.4^{a}	85.1	100.2^{a}	131.5^{a}	110.1	120.8^{a}
N	***	***	***	***	ns	***	***	ns	***
P_2O_5 kg ha^{-1}									
23	54.3	31.4	42.9	94.0	80.2	87.0	106.3	102.7	104.5
46	54.5	32.2	43.4	101.8	81.2	91.6	116.3	109.0	112.7
69	55.0	32.2	43.6	98.1	78.5	88.3	112.3	105.6	109.0
(0:0) NP	50.8	30.9	40.8	93.8	77	85.4	105.5	107.3	106.4
CV (%)	8.9	9.6	10.5	15.2	16.4	16.4	17.2	19.1	18.8

Note**:** Means in a column that have similar superscript letters exhibit no significant variation at $p \geq 0.05$, *** = highly significant ($p < 0.001$), ns = non-significant.

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Tuber number

In this experiment, nitrogen had a significant effect on tuber number ($P < 0.01$) (Table 2). The addition of 92 kg N ha^{-1}produced the greatest marketable and overall tuber numbers, with 100.2 and 120.8 tubers per plot, respectively. These results were significantly higher than the control group, which yielded 85.4 marketable and 106.4 total tubers per plot (Table 3). This rate of nitrogen application led to a 17.3% increase in marketable tubers and a 14% increase in total tubers compared to the control. Consistent with this result, several researchers have confirmed that the addition of nitrogen increases the number of tubers formed (Fayera Wakjira, 2017; Nuru Seid and Tenalem Misgan, 2019). As reported by Israel Zewide et al. (2012), increasing N fertilization to 165 kg ha^{-1} boosted saleable tube numbers by 56.36% and overall tuber numbers by 31.7%. Similarly, Yadav et al. (2022) reported that, compared with the control, the addition of 225 kg N ha^{-1} improved the overall tuber number by 19.2%. According to Anning et al. (2023), the same nitrogen application rate resulted in increases in tuber numbers of 21.8% and 21.1% for the 2018 and 2019 growth periods, respectively.

In this study, phosphorus fertilization did not significantly influence tuber numbers. Although the highest count of marketable tubers (91.6) was observed with 46 kg ha^{-1} P_2O_5, this did not statistically vary from other rates (Table 3). This may be due to the medium range of available phosphorus already present in the soil. This finding aligns with reports from Jasim et al. (2020) and Habtam Setu and Mitiku (2020). In this research, combining nitrogen and phosphorus fertilizers also had no significant impact on the saleable or overall tubers. Additionally, the amount of unmarketable tubers showed no significant response to nitrogen, phosphorus, or their interaction (Table 2). Likewise, Zelalem et al. (2009) and Birtukan Belachew (2016) found that phosphorus fertilizer didn't affect the quantity of unmarketable or total tubers.

Tuber yield

The study revealed that different nitrogen rates markedly affected total and marketable potato yields in both years (2020-2021). The combined analysis also showed that nitrogen application rates caused a meaningful impact on tuber yield. The saleable yield increased from 25.85 to 36.61 tons ha^{-1} in the first year and from 11.50 to 14.38 tons ha^{-1} in the second year when the nitrogen level was raised from 0 kg ha^{-1} to 92 kg ha^{-1} (Table 4). This is because nitrogen improves leaf growth, photosynthesis, and nutrient use efficiency, which together promote better tuber formation and increase marketable yield (Anas et al., 2020). These yield increases are supported by positive associations of marketable tuber yield with plant height ($r=0.92$) and number of tubers ($r = 0.75$), indicating that the effect of nitrogen on growth traits contributes directly to higher yields (Figure 5). The combined analysis revealed that the maximum total tuber yield (25.5 tons ha^{-1}) was obtained from 92 kg N ha^{-1}, followed by 23.22 tons ha^{-1}, which was achieved at the 69 kg ha^{-1} N level, resulting in a tuber yield increase of 36% and 24%, respectively, compared with those in the control treatment. Similarly, Anning et al. (2023) and Yadav et al. (2022) confirmed that the addition of 225 kg ha^{-1} N led to 54.3% and 34.2% sealable yield increases, respectively.

According to Tadele Amare et al. (2022b), tuber yields of potato significantly increase with increasing nitrogen application rates. In another study, Workat Sebnie et al. (2021) noted that potato marketable yield rose from 20.6 to 45.5 tons ha^{-1} as N addition rose from 0 to 138 kg ha^{-1}. The positive impact of nitrogen on tuber yield has been widely acknowledged (Birtukan Belachew, 2016; Fayera Wakjira, 2017; Kurka and Shumbulo, 2022; Solomon Fantaw et al., 2019; Zhang et al., 2024). These studies reported that increasing N fertilizer addition directly enhances potato tuber yield under both rainfed and irrigated conditions. This research found that applying 69 kg ha^{-1} P_2O_5 produced the greatest sealable and total tuber yields at 22.71 and 23.25 ton ha^{-1}, respectively (Table 4). However, the yield variation among the P_2O_5 rates was not significant ($p < 0.05$), which might be because of moderate phosphorus availability (Table 1), indicating a limited yield response to phosphorus application. However, the yield difference in the control and the lowest P rate of 23 kg ha^{-1} P_2O_5 was larger (Table 4). Similarly, Workat Sebnie et al. (2021) found that applying more than 23 kg P_2O_5 ha^{-1} did not significantly boost yields. In a similar finding, Yohannes Gelaye et al. (2021) achieved the highest marketable yield by applying 34.5 kg P_2O_5 ha^{-1}. Tadele Amare et al. (2022b) also indicated that phosphorus had a relatively minor impact on tuber yield in contrast to nitrogen. The joint effect of N and P did not significantly affect either marketable or total tuber yield during either *Belg* season (Table 2). This study aligns with the findings of Habtam Setu and Mitiku (2020), who reported no significant interaction effect of nitrogen and phosphorus on potato growth and yield. Moreover, phosphorus rates did not significantly affect most of the potato's yield or yield-related parameters. In this research, unsaleable tuber yield remained unaffected by nitrogen, phosphorus, or their combined application. Similarly, Israel Zewide et al. (2012) reported that nitrogen did not affect the unmarketable yield, whereas Niguse Abebe (2016) reported that phosphorus fertilization failed to significantly affect the yield of unsaleable tubers.

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Table 4. Potato tuber yield performance under nitrogen and P_2O_5 rates in Asagirt district, North Shewa, Ethiopia.

N or P Rates	Marketable yield (ton ha^{-1})			Overall tuber yield (ton ha^{-1})		
	2020	2021	Average	2020	2021	Average
N kg ha^{-1}						
23	28.62^{b}	11.54^{c}	20.08^{c}	29.07^{b}	11.98^{c}	20.52^{c}
46	29.22^{b}	12.35^{bc}	20.78^{bc}	29.86^{b}	12.84^{bc}	21.35^{bc}
69	33.05^{ab}	13.38^{ab}	23.22^{ab}	33.56^{ab}	13.87^{ab}	23.72^{ab}
92	36.61^{a}	14.38^{a}	25.50^{a}	37.27^{a}	14.87^{a}	26.07^{a}
N	**	***	***	**	***	***
P_2O_5 kg ha^{-1}						
23	31.61	12.77	22.19	32.12	13.18	22.65
46	31.52	13.04	22.28	32.12	13.56	22.84
69	32.49	12.93	22.71	33.07	13.43	23.25
(0:0) NP	25.85	11.5	18.68	26.38	11.91	19.14
CV (%)	20	15.9	24	19.9	14.4	23.7

Note: Means in a column that have similar superscript letters exhibit no significant variation at $p \geq 0.05$, *** = significant ($p < 0.001$), **= significant at $p < 0.01$, ns = non-significant.

Figure 4. Field performance of potato during the initiation of tubers at Asagirt district site 1.

Correlation analysis

As shown in Figure 5, the association assessment suggested that plant height was strongly and absolutely related to the sealable tuber number, overall tuber number, sealable tuber yield, and overall tuber yield. However, it shows a significant negative association with unmarketable tuber numbers. In addition, the number of total and marketable tubers was positively linked to the corresponding yields. These results indicate that most potato growth and yield traits play key roles in increasing saleable tuber yield, which is highly positively related with plant height (r = 0.92), marketable number of tubers (r = 0.75), and overall number of tubers (r = 0.46).

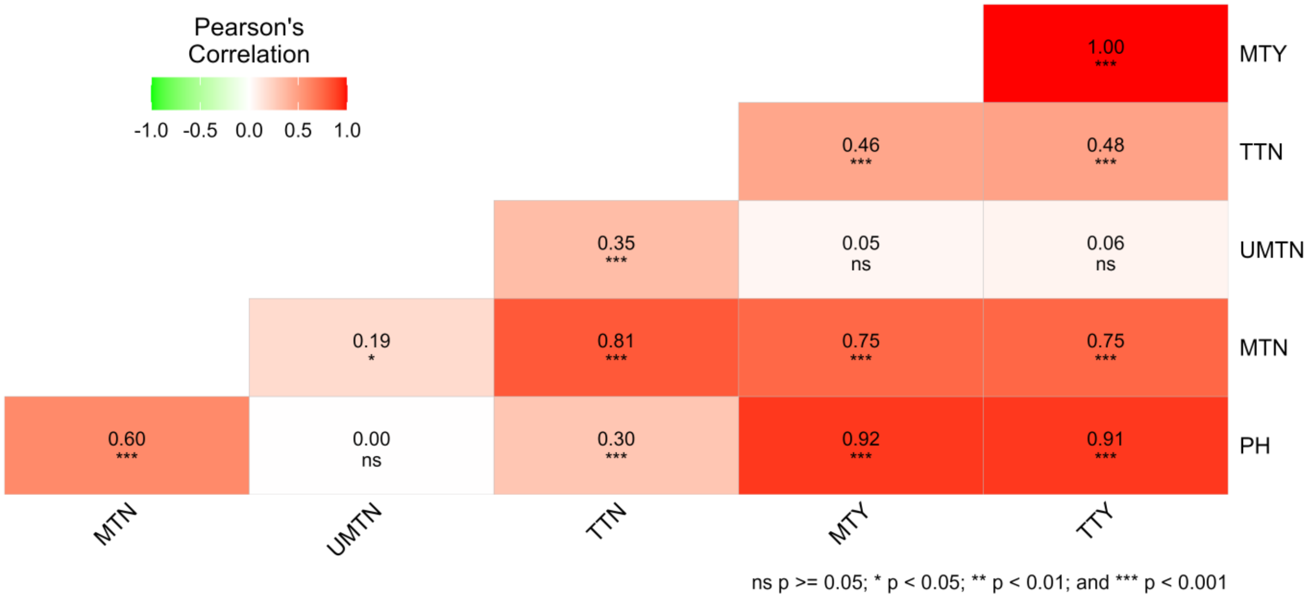

Figure 5. Correlation analysis of the impacts of N and P_2O_5 rates with respect to growth and potato yield parameters growing in Asagrt district of North Shewa, Ethiopia.

where PH = plant height, MTN = marketable tuber number (Saleable), UMTN = unmarketable tuber number (unsaleable), TTN = total tuber number, MTY= marketable tuber yield, and TTY= total tuber yield (overall).

Economic analysis

To perform the economic analysis (Table 5), the marketable yield of potatoes was adjusted downward by 10% to account for the proper addition of fertilizer (5%) and the effect of mini plot sizes (5%), which vary between a research field and a farmer's experimental field (CIMMYT, 1988). Based on Mishan and Quah (2020), the financial analysis compared various N and P_2O_5 treatment combinations for gross benefit, total costs, and net income. The 92:46 N and P_2O_5 combination yielded the highest benefit-cost ratio of 2.67, followed by the 92:69 N and P_2O_5 combination, with a

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B:C ratio of 2.57. Thus, applying 92 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} is both profitable and advised for farmers in Asagirt and similar agroecological regions during the *Belg* season.

Table 5. Economic analysis and benefit–cost ratio of different N and P_2O_5 fertilizer treatments.

Treatment	Adjusted MTY (kg ha^{-1})	Farm gate price of potato (ETB kg $^{-1}$)	Gross benefit (ETB ha $^{-1}$)	Total cost (ETB ha $^{-1}$)	Net Income (ETB ha $^{-1}$)	B: C ratio
0 N*0 P_2O_5	18680.0	10	186800	93750	93050	1.99
23 N*23 P_2O_5	20750.0	10	207500	95470	112030	2.17
23 N*46 P_2O_5	19190.0	10	191900	96218	95682	1.99
23 N*69 P_2O_5	20290.0	10	202900	96944	105956	2.09
46 N*23 P_2O_5	22660.0	10	226600	96464	130136	2.35
46 N*46 P_2O_5	20280.0	10	202800	97190	105610	2.09
46 N*69 P_2O_5	19810.0	10	198100	97938	100162	2.02
69 N*23 P_2O_5	21470.0	10	214700	97436	117264	2.20
69 N*46 P_2O_5	23120.0	10	231200	98184	133016	2.35
69 N*69 P_2O_5	25060.0	10	250600	98933	151667	2.53
92 N*23 P_2O_5	24270.0	10	242700	98475	144225	2.46
92 N*46 P_2O_5	26520.0	10	265200	99156	166044	2.67
92 N*69 P_2O_5	25700.0	10	257000	99904	157096	2.57

Note: Price of N = 35.4 ETB kg $^{-1}$, price of P_2O_5 = 24.7 ETB kg $^{-1}$, market price of potato = 10 ETB kg^{-1}, ETB = Ethiopian birr, MTY = marketable tuber yield (kg ha^{-1}), B:C ratio = benefit–cost ratio.

Conclusions

The findings of this study provide critical insights into the role of N and P fertilization on potato performance and productivity in Asagirt District and similar agroecologies. The presowing soil analysis revealed that the soils were moderately acidic with low total nitrogen and organic carbon contents, conditions that require external nitrogen application for optimal potato growth. In contrast, the available soil phosphorus level was moderate. Moreover, the application of nitrogen fertilizer plays an important role in maximizing plant height, tuber number, and tuber yield. The results showed that applying up to 92 kg N ha^{-1} nitrogen markedly enhanced growth and yield, resulting in a 36% increase over the control. Among the P_2O_5 rates, the greatest marketable yield (22.71 tons ha^{-1}) was achieved at 69 kg P_2O_5 ha^{-1}, but this difference was not statistically significant. This may be due to the substantial amount of soil phosphorus at the study sites, further highlighting the relevance of location-specific fertilizer recommendations. The economic analysis confirmed that the joint addition of 92 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} resulted in the greatest net profit of 166,044 ETB ha^{-1} and the maximum benefit-cost ratio of 2.67, contributing significant economic benefits for farmers. Hence, the combined addition of 92 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} is recommended as an optimal fertilizer rate for potato production in Asagirt and similar agro-ecologies during the Belg season until further N and P rates are determined through multilocation studies.

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Author contributions

Y.G. Conceptualized the study, conducted the research, interpreted the results, and wrote the paper. S.A., G.S., L.G., B.S., K.K., G.L., and G.T. contributed to the investigation, data collection, writing, and review, and the provision of resources (reagents and materials).

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Data availability statement

All collected data generated during this study are available by contacting the correspondence author.

Competing interest

We affirm the absence of any financial or personal interests.

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