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Original Paper

Optimizing Nitrogen and Phosphorus Fertilization for Enhanced Potato (Solanum tuberosum L.) Production in Chilga District, Ethiopia

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Abstract*—Potato (Solanum tuberosum L.) is a strategic crop in Ethiopia with high potential to improve food security, household income, and rural livelihoods. However, productivity is constrained by poor soil fertility and uncertain inorganic fertilizer application. The study was conducted during the main rainy seasons of 2018/2019 and 2019/2020 in the Chilga District of the Amhara Region, Ethiopia, to optimize nitrogen (N) and phosphorus (P) fertilization. A factorial randomized complete block design with three replications, four rates of N (0, 46, 92, and 138 kg ha^{-1}), and three rates of P_2O_5 (0, 46, and 69 kg ha^{-1}) was replicated across four farmers' fields using the Gudene potato variety. The analysis of variance revealed that (N) fertilization significantly influenced phenology and growth traits. Both N and P fertilization enhanced marketable and total tuber yields. Nitrogen application increased marketable yield from 13.0 to 24.2 t ha^{-1}, and phosphorus application enhanced from 15.8 to 20.5 t ha^{-1}. Partial budget analysis also identified the combined application of 138 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} as the most profitable, yielding a 169,976 ETB ha^{-1} net benefit and a 5491.7% marginal rate of return, with a 140% yield advantage over the control. For the time being, the current rates of NP application are recommended for maximizing potato productivity and profitability in the Chilga district and similar agro-ecological zones. Future research should explore maximum rates of these nutrients to determine their potential impact on yield and to identify optimal levels for maximizing potato productivity.

Keywords*—Marketable Yield, Partial Budget Analysis, Plant Height, Tuber Yield

I. INTRODUCTION

Potato (Solanum tuberosum L.) is an herbaceous plant species belonging to the family Solanaceae and classified within the genus Solanum. Native to South America. It originated in the Andean region, particularly present-day Peru and Bolivia [1]. The crop was introduced to Ethiopia in 1859 by the German botanist Schimper [2]. Initially, potato cultivation in Ethiopia was limited to homesteads and remained limited for many years. Among root and tuber crops, potatoes rank first in Ethiopia in terms of production and consumption, followed by cassava, sweet potatoes, and yams [3]. It has substantial potential to contribute to the national economy, enhance food security, and improve smallholder farmers' income through value-added products [4]. The crop is also economically attractive, with returns on cash investment exceeding 100% and returns on family labor surpassing the opportunity cost of work [5].

In the Ethiopian highlands, potato holds great potential for improving the livelihoods of millions of smallholder farmers [6]. Its high-yielding potential, early maturity, and excellent nutritional value make it a strategic crop for enhancing food security, increasing household income, and reducing poverty [7]. The short vegetative period further allows farmers to cultivate potatoes under diverse weather conditions and unpredictable climates [3].

Recent statistics indicate that Ethiopia produces approximately 3.6 million tons of potatoes annually from about 300,000 hectares, with an average yield of 12 t ha^{-1}, which remains well below the global average of 20 t ha^{-1}. Over the past decade, the area under potato cultivation has expanded significantly, from 200,000 ha in 2013 to 300,000 ha in 2023, reflecting its growing role in the agricultural economy [8], [9], [10], [11]. However, productivity continues to reduce due to constraints imposed by poor soil fertility, uncertain inorganic fertilizer application, limited access to quality seed, climate variability, and pest and disease pressures [12], [13].

Soil fertility deterioration is a major constraint to potato production in Ethiopian highlands [14]. Continuous cropping, lack of fallowing, use of manure for fuel consumption, and absence of crop rotation have severely depleted soil nutrients in Ethiopia [14], [15]. Ethiopian farmers have to address these challenges by applying both organic and inorganic fertilizers to improve crop production and soil fertility [16], [17]. Recent studies highlighted persistent problems, including poor soil fertility, limited access to certified seed, and suboptimal agronomic practices [17], [18], [19]. A soil assessment conducted in 2020 in the central highlands of Ethiopia indicated that 70% of potato fields exhibited significant deficiencies in nitrogen and phosphorus. [8]. Soil acidification, primarily resulting from the over-application of ammonium-based fertilizers, is an emerging concern. Additionally, practices such as mono-cropping and

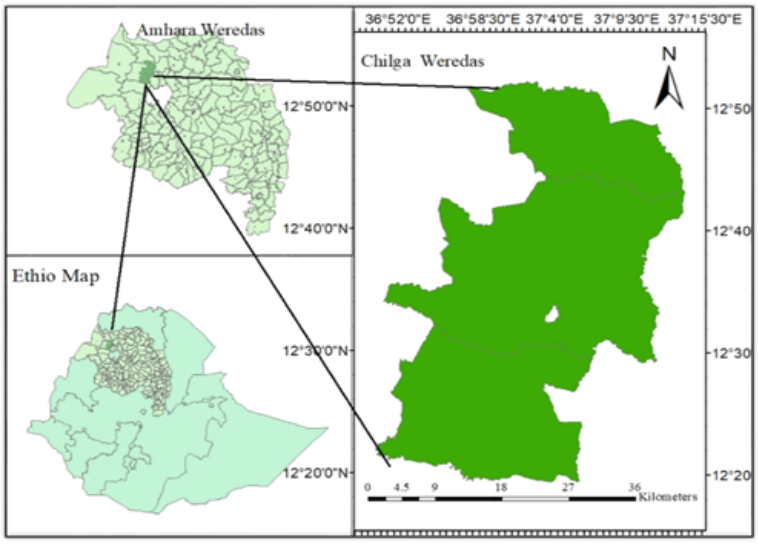


Fig. 1. Map of the study area

Source: This map was prepared using ArcGIS software, with shape files obtained from [25] sources

the minimal use of fertilizers contribute to the decline in long-term soil productivity [14], [20]. Potato is highly responsive to nitrogen fertilization, which is often the most limiting nutrient, particularly in sandy soils [21], [22]. However, excessive nitrogen application can reduce tuber quality, delay maturity, and divert dry matter accumulation to aerial parts rather than tubers [22], [23].

Therefore, the development of improved fertilization strategies with appropriate nitrogen concentrations is essential for sustainable potato production. Experimental evidence in Ethiopia demonstrates that nutrient application significantly enhanced potato tuber yield [24]. Given these challenges, optimizing soil fertility management is a critical priority for improving potato productivity in Ethiopia. Therefore, the present study was initiated to determine the optimum rate of nitrogen and phosphorus fertilizers required to enhance tuber yield in the Chilga district, Ethiopia.

II. Materials And Methods

A. Description of Study Area

The field study was conducted during the 2018/2019 and 2019/2020 cropping seasons on four farmers fields in the Chilga District of the Amhara National Regional State, Ethiopia (Fig. 1). The district lies between 12°20′N to 12°50′N latitude and 36°52′E to 37°15′E longitude with an altitude of about 2,146 meters above sea level

B. Climatic Conditions

Chilga district features a highland to midland agro-ecology with moderate temperatures and unimodal rainfall patterns conducive to mixed farming systems. Its soil type is typically nitosols and vertisols, which are moderately fertile and suitable for crop production [26]. Its soils support staple crop production and livestock rearing [27]. The local climate is characterized by minimum and maximum temperatures of 12.4°C and 28 °C, respectively, with an average annual rainfall of approximately 1177.2 mm (Fig.2). These mean annual rainfalls are generally sufficient for potato production, provided that rainfall is well distributed during the growing season and soil moisture is adequately conserved [28]. In general, rainfall during the main rainy season (July, August, and September) contributes the highest percentage of rainfall in the region [29]. The maximum and minimum temperatures are generally higher from March to December.

C. Planting Materials, Experimental Design, and Methods of Application

An adapted and recommended variety of Irish potato called the Gudene variety was used for an experimental crop in the main season. Seed tubers of the potato were standardized before planting by selecting healthy, disease-free tubers of similar physiological age and a uniform weight range across all treatments. The treatment had three levels of phosphorus (0, 46, and 69) and four levels of nitrogen (0, 46, 92, and 138) kg ha-1 used. Twelve treatment combinations were randomly replicated three times on four farmers' fields in a factorial randomized complete block (RCB) design. The source of nitrogen was in the form of urea, while P was in the form of Triple Superphosphate (TSP). All dosage of phosphorus was applied at planting. Nitrogen was applied in a split application, with half applied at planting and the other half at the flowering stage. The experimental plot had a gross area of 2.8 m by 2.4 m (6.72 m²), while the net harvested area measured 2.4 m by 1.4 m (3.36 m2), corresponding to two rows. Each plot was established with four rows, containing eight plants per row. Planting geometry was maintained at 70 cm inter-row spacing and 30 cm intra-row spacing. To minimize edge effects and ensure experimental uniformity, plots were separated by 1.0 m, and blocks were spaced at 1.5 m intervals.

D. Data Collection

Data were recorded on key agronomic and economic parameters from the central rows of each experimental plot. The agronomic variables included date of flowering, date of physiological maturity, number of tubers per hill, number of

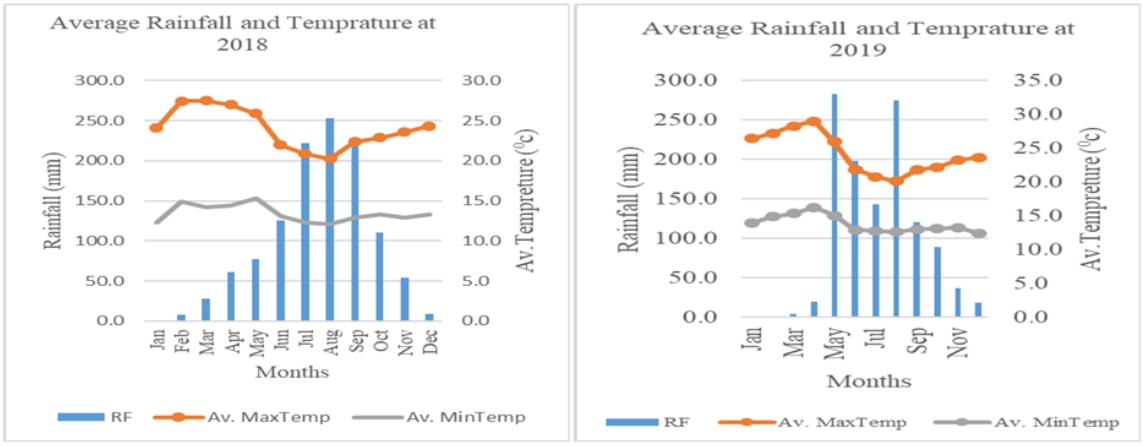


Fig. 2. Mean monthly rainfall and temperature of Chilga district in the 2018 and 2019 cropping seasons

Source: From Chilga meteorological station

stems per plant, plant height (cm), marketable yield (t ha^{-1}), and total yield (t ha^{-1}) were collected. Economic data were also collected: fertilizer prices (ETB) were documented at the time of planting, while farm-gate potato prices (ETB) were recorded at harvest.

E. Statistical Analysis

The experimental design was a randomized complete block design (RCBD) with treatments considered as fixed effects and blocks as random effects. Prior to combined analysis, the dataset was evaluated for normality and homogeneity of variances using the Shapiro–Wilk and Bartlett's tests, respectively, and screened to ensure compliance with ANOVA assumptions. Bartlett's test confirmed homogeneity of variances across locations, allowing data pooling for combined analysis. The combined ANOVA revealed a significant location effect but a non-significant location × treatment interaction, indicating that fertilizer treatment responses were consistent across locations. Statistical analyses were performed using SAS software, version 9.0 [30]. Separate ANOVA models were fitted for each site and year, followed by a combined analysis across sites and years to evaluate overall treatment effects. When significant differences among treatments were detected ($p < 0.05$), mean separation was conducted using the Least Significant Difference (LSD) test at the 5% probability level. Using Fisher's Least Significant Difference (LSD) provides adequate sensitivity for treatment comparison and remains widely accepted in agricultural field research.

F. Partial Budget Analysis

A partial budget analysis was conducted for each treatment following the methodology outlined by [31] to evaluate the economic advantage of alternative fertilizer treatments compared with the control. Fertilizer costs and the mean farm-gate price of potatoes were obtained from the respective district. Total variable costs were estimated using the prevailing market prices of nitrogen (N) and phosphorus (P) fertilizers at the time of planting, while the value of potato tuber yield was calculated using the average farm-gate price at harvest.

The average costs of fertilizers during the 2018/2019 and 2019/2020 main cropping seasons were 17.91 ETB kg^{-1} for urea and 13.27 ETB kg^{-1} for Nitro-Phospho-Sulphate (NPS), and the average market price of potatoes was 7.00 ETB kg^{-1}. To account for the difference between experimental yields and farmers' field performance, the average potato tuber yield was adjusted downward by 10%.

Dominance analysis was applied to exclude economically inferior fertilizer treatments before profitability assessment. Marginal rate of return (MRR) was then calculated as the key economic criterion. An MRR of ≥100% was considered the minimum acceptable threshold, ensuring that each unit of cost generated at least one unit of net benefit. Practices exceeding this threshold were deemed economically viable, while those below were not recommended due to insufficient cost recovery. The marginal rate of return was calculated as shown in (Eq. 1).

$$MRR\ (\%) = (\Delta MB/\Delta MC) \times 100 \quad (1)$$

Note

MRR = Marginal Rate of Return

ΔMB = change of marginal benefit

ΔMC = change of marginal cost

$$NB = GB - TVC \quad (2)$$

Note

GB = (MYD × Price of potato)

TVC = Total Variable Cost of NP fertilizers.

$$AMYD = MYD - (MYD \times 10\%) \quad (3)$$

NB = Net Benefit

GB = Gross Benefit

AMYD = Adjusted Marketable Yield

MYD = Actual marketable Yield

G. Sensitivity Analysis

Following the methodology of the International Maize and Wheat Improvement Center (CIMMYT) [31], a sensitivity

analysis was performed to evaluate the robustness of the fertilizer recommendation under potential fluctuations in input and output prices. Fertilizer costs were increased by 20% and potato market prices were decreased by 20%, both individually and in combination. The results showed that the recommended fertilizer rate consistently generated the highest net benefit and maintained a marginal rate of return above the minimum acceptable level of 100% under all scenarios. This demonstrates that the recommendation is economically stable and resilient to reasonable variations in fertilizer and potato prices.

H. Soil Sampling and Analysis

Composite soil samples were collected in a diagonal pattern at a depth of 0–30 cm before planting for each site. Total nitrogen was determined using the Kjeldahl method [32], and available phosphorus was determined according to the Olsen procedure [33]. Soil pH was determined in a 1:2.5 soil to water suspension following the procedure outlined by [34]. Soil organic carbon content was determined by the wet digestion method using the Walkley and Black procedure [35]. The exchangeable potassium was measured by a flame photometer after extraction of the samples with an ammonium acetate solution at pH 7, following the procedures described by [36]. Soil particle size is determined by the density of soil-water suspension measured with the Bouyoucos hydrometer method [36].

III. Results And Discussion

A. Physicochemical Properties of Soil in Study Sites

Based on the results of the soil analysis (TABLE I), both four different sites in two years exhibited a soil pH range from 5.33 to 5.73, classified as moderately acidic [37]. Organic carbon levels ranged from 1.71 to 2.75%, which is considered medium by Tekalign [38]. Available phosphorus (5.83 to 11.65 ppm) was rated low to medium [39], while total nitrogen content (0.2 to 0.34%) was within moderate to high levels [38]. The cation exchange capacity (CEC) of the soil was measured to range from 34.11 to 43.01 cmol kg^{-1} of soil, indicating a high capacity for cation retention. The levels of exchangeable cations were as follows: exchangeable potassium (Ex. K^+) ranged from 0.35 to 1.15 Cmol kg^{-1} of soil, classified as medium to high; exchangeable sodium (Ex. Na^+) ranged from 0.33 to 0.63 Cmol kg^{-1} of soil, categorized as medium; exchangeable calcium (Ex. Ca^{2+}) ranged from 11.5 to 23.33 Cmol kg^{-1} of soil, indicating high to very high levels; and exchangeable magnesium (Ex. Mg^{2+}) ranged from 8.99 to 16.16 Cmol kg^{-1} of soil, classified as very high [40]. Moderate levels of soil organic carbon (SOC), total nitrogen, and available phosphorus limit the availability of nutrients such as nitrogen and phosphorus [37]. Therefore, to achieve optimal potato production, these nutrients need to be supplied through synthetic and organic fertilizers. The soil texture was classified as clay and clay loam.

TABLE I. Soil Physicochemical Properties

Soil properties	**Unit**	**2018**		**2019**	
		Site 1	***Site 2***	***Site 3***	***Site 4***
Total nitrogen	%	0.21	0.25	0.2	0.34
Available P	P/PPM	5.83	5.95	10.28	11.65
pH	H_2O (1:2.5)	5.73	5.33	5.45	5.67
OC	%	1.71	1.87	2.75	2.13
CEC	Cmol kg^{-1} Ammon. Acet.	41.45	43.01	34.11	35.14
Ex. K+	Cmol/kg Ammon. Acet.	1.15	0.72	0.35	0.63
Ex. Na+	Cmol/kg Ammon. Acet.	0.3	0.37	0.33	0.63
Ex.Ca+	Cmol/kg Ammon. Acet.	11.5	17.9	15.52	23.33
Ex. Mg+	Cmol/kg Ammon. Acet.	13.1	7.2	16.16	8.99
Soil Proportion					
Sand	%	31.28	29.28	24.72	26.72
Clay	%	30	32	46	36
Silt	%	38.72	38.72	29.28	37.28
Textural class	%	clay loam	Clay loam	Clay	Clay loam

B. Days to flowering and physiological maturity

The number of days to 50% flowering and physiological maturity was significantly different ($p < 0.05$) and ($p < 0.01$), respectively, influenced by nitrogen fertilization. In contrast, the interaction effect between nitrogen (N) and phosphorus (P) was not statistically significant (TABLE II). Days to 50% flowering were delayed by approximately three days when nitrogen application increased from 0 to 138 kg N ha^{-1}. Similarly, phosphorus fertilization significantly postponed dates of flowering by three days when the rate increased from 0 to 69 kg P_2O_5 ha^{-1} compared to the control. Maturity date was significantly affected only by nitrogen fertilization, with a postponement of 10 days observed as the nitrogen rate increased from 0 to 138 kg N ha^{-1}.

The observed delay in flowering and maturity with increasing nitrogen levels might be attributed to enhanced nitrogen uptake, which stimulates chlorophyll synthesis and promotes vigorous vegetative growth of potatoes. This extended canopy development prolongs the photosynthesis period, thereby delaying the transition to reproductive growth to tuber bulking. Higher rates of phosphorus application have been shown to stimulate root propagation, particularly the development of lateral and fibrous rootlets. This enhanced root system improves the plant's capacity to absorb water and essential nutrients, thereby sustaining vigorous aboveground vegetative growth [41].

The findings of these studies are consistent with [42], who reported that increasing nitrogen application from 0 to 207 kg N ha^{-1} significantly delayed both flowering and maturity. Similarly, [43] observed that nitrogen fertilization had a pronounced effect on phonological traits, delaying flowering and maturity by 7 and 12 days, respectively, when the nitrogen rate increased from 0 to 138 kg N ha^{-1}. The results are further supported by [44], who demonstrated that days to maturity were significantly influenced by the main effect of nitrogen rather than the nitrogen (N) and phosphorus (P) interaction. Other findings, Niguse [45] reported that

phosphorus fertilization significantly affected the number of days to flowering, delaying it approximately three days at an application rate of 89.7 kg P_2O_5 ha^{-1}.

C. Plant Height

Analysis of variance indicated that nitrogen (N) application significantly influenced potato plant height, whereas phosphorus (P) did not exert a measurable effect (TABLE II). The shortest plant height (44.6 cm) was observed in the unfertilized plot (0 kg N ha^{-1}), while the tallest plants (62.8 cm) were recorded at 138 kg N ha^{-1}. Thus, nitrogen fertilization at 138 kg N ha^{-1} increased plant height by 18.2 cm compared to the control. The increase in plant height can be attributed to enhanced stem elongation stimulated by nitrogen availability.

Nitrogen fertilizer significantly affects potato plant height because it plays a central role in vegetative growth. Adequate nitrogen supply increases chlorophyll concentration and enhances photosynthetic capacity, which promotes stem elongation, all of which contribute to taller plants relative to unfertilized plots. These physiological effects explain the consistent positive response of potato height to nitrogen fertilization [46], [47].

These findings are consistent with the results of [42], who reported that nitrogen fertilization significantly increased potato height as a result of enhancement of photosynthetic capacity and stem elongation. Similar conclusions were drawn by [48-50], all of whom documented that increasing nitrogen levels significantly enhanced potato plant height. Collectively, these studies confirm that nitrogen fertilization consistently promotes vegetative growth and height development in potato.

D. Number of stems per hill

The analysis of variance indicated that the number of stems per hill was not significantly affected by nitrogen and phosphorus (NP) rates or their interaction (TABLE II). This outcome is likely because stem initiation in potatoes is primarily governed by seed tuber size, eye number, and physiological age rather than external nutrient supply [51]. Moreover, the experimental soil contained moderate to high levels of native nitrogen (0.20–0.34%), which was sufficient to support stem development without additional fertilization [38]. As a result, NP application enhanced vegetative vigor but did not alter stem number, underscoring the dominant role of seed tuber characteristics and inherent genetic factors, physiological age, and sprout number in regulating this trait. Therefore, fertilizer application had limited influence on this trait, despite its significant effects on other growth and yield parameters.

Similar findings were reported by [52], who concluded that the stem number per hill was not significantly influenced by NP fertilization, attributing this to adequate native soil fertility and the genetic control of stem initiation. Likewise, [51] observed that NP application improved vegetative growth, yet stem number remained largely unchanged, a response attributed to the genetic and physiological characteristics of the seed tubers. The findings of the present study contrast with those of [53], who reported that nitrogen (N) and phosphorus (P) individually influenced stem number per hill, though their interaction did not, in trials conducted at Dabat and Debark. In that study, NP application rates of 110/90 kg ha^{-1} significantly enhanced stem numbers. The highest stem counts were recorded at Debark (5.88 stems per hill with 165 kg N ha^{-1}) and at Dabat (5.12 stems per hill with 110 kg N ha^{-1}), indicating that higher nitrogen levels can stimulate stem initiation under those conditions

TABLE II. EFFECT OF NITROGEN AND PHOSPHORUS FERTILIZERS ON PHENOLOGY AND GROWTH OF POTATOES

Nitrogen (kg ha^{-1})	**DF**	**DM**	**Ph. (cm)**	**NS./hill**
0	60.4^{b}	115.1^{c}	44.6^{c}	6.71
46	61.4^{b}	120.7^{b}	49.5^{c}	6.38
92	63.1^{a}	122.9^{a}	56.0^{b}	6.58
138	63.6^{a}	125.1^{a}	62.8^{a}	6.63
LSD (0.05)	*	**	*	NS
P_2O_5 (kg ha^{-1})				
0	62.4^{b}	6.48	52.28	6.48
46	62.5^{b}	6.44	52.53	6.44
69	65.1^{a}	6.81	54.93	6.81
LSD(0.05)	*	ns	ns	ns
CV (%)	3.2	3.7	16.3	17.8

Notes -* = significant at p <0.05, ** = highly significant at p<0.01, DF = Date of 50% flowering, DM = Date Maturity, ns = non-significant, NS/hill=Number of stem per hill, Ph. = plant height (cm),

E. Number of tubers per hill

The number of tubers per hill was significantly increased by nitrogen (N) fertilization; the application of phosphorus (P) fertilization did not affect it (TABLE III). As N rates rise, tuber number per hill also increased, with the highest count (8.9 tubers per hill) recorded at 138 kg N ha^{-1} and the lowest (5.9 tubers per hill) observed under unfertilized conditions. This response may be explained by the role of nitrogen in stimulating vegetative growth and assimilate supply before tuber initiation, thereby enhancing tuber number per plant. These findings indicate that appropriate nutrient management in soils can substantially increase tuber number, which is a critical determinant of potato productivity. Similar results have been reported in Ethiopia [52], which observed that nitrogen application significantly increased tuber number and yield components in southwestern Ethiopia. Author [24] emphasized that nitrogen fertilization enhances vegetative vigor and tuber formation, while [51] also confirmed that optimal N rates improved tuber number without altering stem count, highlighting the importance of balanced nutrient supply. According to [38], adequate nitrogen availability is essential for maximizing potato growth and tuber production.

Similar findings of [42], who stated that increased rates of nitrogen (N) and phosphorus (P) significantly increased the average tuber number per hill of potato due to differences in the growth conditions. The result is also comparable to that of [54], who confirmed that N nutrient significantly affects tuber formation via influencing the biosynthesis of gibberellins and the balance of phytohormones in potato plants. In contrast, [55] reported that the number of potato tubers per hill significantly responded to phosphorus (P), and the highest number of tubers per hill, 9.6, was recorded at the level of 90 kg P_2O_5 ha^{-1}.

F. Marketable and total tuber yield of potatoes

Nitrogen (N) fertilization significantly ($p < 0.01$) influenced both marketable and total tuber yield of potatoes. Similarly, phosphorus (P) fertilization significantly ($p <$

0.05) influenced both marketable and total tuber yield of potatoes. However, their interaction effect was not statistically significant (TABLE III). This indicates the response to each nutrient was largely independent and additive. This may be attributed to the initial soil nutrient status, which allowed both nutrients to contribute separately to crop growth and yield. Marketable yield increased from 13.0 to 24.2 t ha^{-1} as N rates rose from 0 to 138 kg ha^{-1}. Similarly, marketable yield increased from 15.8 to 20.5 t ha^{-1} with P_2O_5 application from 0 to 69 kg ha^{-1}. The highest marketable yields were obtained at 138 kg N ha^{-1} (24.2 t ha^{-1}) and 46 kg P_2O_5 ha^{-1} (20.1 t ha^{-1}), while the lowest yields were recorded under an unfertilized plot. Likewise, total tuber yield increased from 13.7 to 25.3 t ha^{-1} with increasing nitrogen from 0 to 138 kg ha^{-1}, and from 16.7 to 21.5 t ha^{-1} with phosphorus application up to 46 kg P_2O_5 ha^{-1}.

The positive response of tuber yield to nitrogen (N) fertilization might be attributed to its role in promoting vigorous vegetative growth, enhanced photosynthetic capacity, and improved nutrient uptake, which collectively increase assimilate supply for tuber bulking. On the other hand, phosphorus (P) supports strong root development and early tuber initiation, thereby contributing to higher yield. These findings highlight the importance of balanced nutrient management for improving potato productivity, consistent with earlier reports that nitrogen and phosphorus are critical determinants of tuber yield in Ethiopian potato production systems [24], [51], [52].

The current findings are in agreement with [56], who recommended the application of 110 kg N ha^{-1} for Ethiopia's major potato-growing regions; however, this rate is lower than the 138 kg N ha^{-1} applied in the present study. In contrast, [57] reported that phosphorus fertilization did not significantly affect potato tuber yield in western Ethiopia, which contradicts our results. Similarly, [55] observed that the highest marketable yield (16 t ha^{-1}) was recorded at nitrogen (N) and phosphorus (P) interaction rate of 110/90 kg ha^{-1}, differing from the outcomes of our experiment. Nevertheless, the present result is supported by the conclusions of [24], who emphasized that adequate NP fertilization is essential for maximizing potato productivity. Our findings also align with those of [42], [48], who demonstrated that higher nitrogen levels significantly enhance tuber yield, reinforcing the importance of balanced nutrient management in potato production systems.

G. Partial Budget Analysis Result

The dominance analysis revealed that the majority of treatments resulted in lower net benefits, which were not statistically significant in terms of potato tuber yield. Consequently, the combinations that exhibited dominance among the treatments were excluded from further consideration. The un-dominated were N and P combination treatments, which gave the highest net benefits in Ethiopian Birr (ETB) with an acceptable marginal rate of returns, which were used as comparable treatments for economic feasibility (TABLE IV). The maximum net benefit (169,976 ETB ha^{-1}) with an acceptable MRR of 5491.7% was recorded from the application of 138/46 kg ha^{-1} of N and P_2O_5 kg ha^{-1}. The combined application of 138/46 kg ha-1 N and P_2O_5 yielded the highest tuber yield of potatoes, provided the highest net benefit, and fell within the acceptable marginal rate of return (MRR). It also gave a 140% yield advantage over the control. Therefore, this study recommends the application of 138/46 kg ha^{-1} of N and P_2O_5 kg ha^{-1} to improve potato productivity and feasibility in Chilga district and similar agro-ecological conditions

Sensitivity analysis result, under the simulated adverse economic scenario (20% reduction in potato price and 20% increase in fertilizer cost), revealed that all fertilizer treatments maintained positive net benefits and marginal rates of return (MRR) well above the minimum acceptable level of 100%, indicating their continued economic viability (TABLE V). Among the treatments, the application of 138 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} consistently performed best, generating the highest adjusted net benefit (133231.2 ETB ha^{-1}) and a marginal rate of return of 3627.8%. These results demonstrate that the recommended fertilizer rate is economically robust, with strong profitability even under unfavorable price conditions, and therefore remains an attractive and low-risk option for farmers across variable market environments.

IV. Conclusion And Recommendation

Nitrogen fertilization exerted a significant influence on potato phenology and growth traits. Increasing N rates delayed flowering by approximately three days and physiological maturity by up to ten days, reflecting extended vegetative growth and canopy development. Plant height responded strongly to N, increasing by 18.2 cm at 138 kg N ha^{-1} compared to the control, while stem number per hill remained unaffected, underscoring the dominant role of seed tuber characteristics and native soil fertility. Tuber number per hill increased significantly with N application, reaching 8.9 tubers at 138 kg N ha^{-1} versus 5.9 under unfertilized conditions. Phosphorus application modestly delayed flowering but had no significant effect on maturity, plant height, or stem number. Nitrogen and phosphorus fertilization significantly enhanced both marketable and total tuber yields, although their interaction effect was not statistically significant. Marketable yield increased from 13.0 to 24.2 t ha^{-1} and total yield from 13.7 to 25.3 t ha^{-1} as N rates rose from 0 to 138 kg N ha^{-1}. Phosphorus fertilization improved yields up to 69 kg P_2O_5 ha^{-1}, with marketable yield rising from 15.8 to 20.5 t ha^{-1} and total yield from 16.7 to 21.5 t ha^{-1}. Economic analysis revealed that the combined application of 138 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} provided the highest net benefit (169,976 ETB ha^{-1}) and an acceptable marginal rate of return (5,491.7%), representing a 140% yield advantage over the control. Therefore, the combined application of N and P, at optimal rates of 138 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}, is advisable for maximizing potato productivity and profitability in the Chilga district and similar agro-ecological zones. Future research should also explore higher rates of these nutrients and their potential impact on yield to identify the optimal levels for maximizing potato productivity and its effect on nutrient use efficiency.

TABLE III. EFFECT OF NITROGEN AND PHOSPHORUS FERTILIZERS ON NUMBER OF TUBERS, MARKETABLE AND TOTAL YIELD OF POTATO

Nitrogen (kg ha^{-1})	**NT per hill**	**MY. (t ha^{-1})**	**TY. (t ha^{-1})**
0	5.9^{c}	13.0^{d}	13.7^{d}
46	7.8^{b}	16.7^{c}	17.7^{c}
92	8.4^{ab}	21.1^{b}	22.2^{b}
138	8.9^{a}	24.2^{a}	25.3^{a}
LSD (0.05)	*	**	**
P_2O_5 (kg ha^{-1})			
0	6.3	15.8^{b}	16.7^{b}
46	8.4	20.1^{a}	20.9^{a}
69	8.4	20.5^{a}	21.5^{a}
LSD(0.05)	ns	*	*
CV (%)	16.8	2.4	27.6

Notes: -* = significant at $p < 0.05$, ** = highly significant at $p < 0.01$, MY = Marketable yield (ton per hectare), ns = non-significant, NT = number of tubers per hill, TY = total tuber yield (ton per hectare)

TABLE IV. DOMINANCE ANALYSIS AND MARGINAL RATE OF RETURN OF NITROGEN AND PHOSPHORUS ON MARKETABLE YIELD OF POTATOES

Treatments (N, P_2O_5) Kg ha^{-1}	**MYD (t ha^{-1})**	**AMYD (t ha- ^{1})**	**TVC (ETB ha^{-1})**	**GB (ETB ha^{-1})**	**NB (ETB ha^{-1})**	**DA**	**MC (ETB ha^{-1})**	**MB (ETB ha^{-1})**	**MRR (%)**
(0,0)	10.9	9.8	0.0	73278.0	73278.0				
(0,69)	12.4	11.2	2687.3	83922.8	81235.5	81235.5	2687.3	7957.5	296.1
(92,0)	16.9	15.2	3819.0	113852.3	110033.3	110033.3	1131.7	28797.8	2544.6
(92,46)	17.7	15.9	5082.5	119252.3	114169.8	114169.8	1263.5	4136.5	327.4
(92,69)	21.0	18.9	6242.3	141527.3	135285.0	135285.0	1159.8	21115.2	1820.6
(138,46)	26.2	23.6	6874.0	176850.0	169976.0	169976.0	631.7	34691.0	5491.7

Notes: AMYD = Adjusted Marketable yield DA = Dominance analysis, ETB = Ethiopian Birr, GB = Gross benefit, MYD = Marketable yield, MC = Marginal Cost, MB = Marginal Benefit, MRR = Marginal Rate of Return, NB = Net Benefit, t ha-1 = ton per hectare, TVC = Total Variable Cost

TABLE V. SENSITIVITY ANALYSIS OF THE PARTIAL BUDGET UNDER A COMBINED SCENARIO 20% DECREASE IN POTATO PRICE AND A 20% INCREASE IN FERTILIZER COST

Treatments (N, P_2O_5) (kg ha^{-1})	**AMYD (t ha- ^{1})**	**ATVC (ETB ha^{-1})**	**AGB (ETB ha^{-1})**	**ANB (ETB ha^{-1})**	**MC (ETB ha^{-1})**	**MB (ETB ha^{-1})**	**MRR (%)**
(0, 0)	9.8	0	58622.40	58622.40			
(0, 69)	11.2	3224.80	67138.20	63913.50	3224.80	5291.10	164.1
(92, 0)	15.2	4582.80	91081.80	86499.00	1358.00	22585.60	1663.10
(92, 46)	15.9	6099.00	95401.80	89302.80	1516.20	2803.80	184.9
(92, 69)	18.9	7490.80	113221.80	105731.10	1391.80	16428.20	1180.40
(138, 46)	23.6	8248.80	141480.00	133231.20	758.00	27500.10	3627.80

Notes: AMYD = Adjusted Marketable yield, Net Benefit, ETB = Ethiopian Birr, AGB =Adjusted Gross benefit, MC = Marginal Cost, MB = Marginal Benefit, MRR = Marginal Rate of Return, NB = , t ha-1 = ton per hectare, TVC = Total Variable Cost

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