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Research Paper

Effect of Blended Fertilizers on Yield Performance of Potato (*Solanum tuberosum L.)* Varieties and Soil Physicochemical Properties in Angacha District, Southern Ethiopia

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Abstract

Soil fertility depletion constrains potato productivity in Southern Ethiopia, where smallholder farmers rarely apply optimal nutrient management or improved varieties. This study evaluated the effects of blended fertilizers on the yield performance of potato (Solanum tuberosum L.) varieties and associated changes in soil physicochemical properties in the Angacha District. A field experiment was conducted at a Farmers Training Center using a factorial randomized complete block design with three replications. Treatments comprised five fertilizer levels (control, 100 kg DAP ha⁻¹, 100 kg NPS ha⁻¹, 100 kg NPKSB ha⁻¹, and 150 kg NPKSBZn ha⁻¹), each combined with a uniform application of 200 kg urea ha⁻¹, and three potato varieties (Gudenie, Digemagn, and Beletach). Results revealed that blended fertilizers significantly improved soil available K, B, and CEC, while slight reductions were observed in soil organic carbon, pH, total N, and available P and S. Significant fertilizer-by-variety interactions influenced yield and yield-related traits. The highest total (48.85 t ha⁻¹) and marketable (46.63 t ha⁻¹) tuber yields, along with the maximum harvest index, were recorded for the Gudenie variety treated with 150 kg NPKSBZn ha⁻¹ + 200 kg urea ha⁻¹. These findings underscore the importance of balanced, multi-nutrient fertilization for enhancing potato productivity and sustaining soil fertility. The application of 150 kg NPKSBZn ha⁻¹ + 200 kg urea ha⁻¹, particularly for the Gudenie variety, is recommended as an optimal nutrient management strategy for the study area and similar agro-ecologies.

1. Introduction

Potato (*Solanum tuberosum L.)* crop production and productivity in tropical countries are constrained by the low fertility status of the soil. However, its production is the fourth highest in the world (Douches, 2013). It is a short-season crop that tolerates a wide range of climatic conditions, with high-yielding varieties exhibiting high nutritional quality that enhances food security (Tewodros et al., 2014). However, its production and productivity are low due to several constraints. For example, in sub-Saharan countries, the yield is 4-7 tons ha-1, whereas in Europe, the yield is 30-40 tons ha-1. This is due

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to farmers' low application of required fertilizers (André et al., 2014).

In Ethiopia, the potato area is about 66,926.00 ha in the Meher season, with 921,403.20 ton production, with less productivity (13.80 t ha-1) compared to the world average of 19.00 t ha-1 CSA, 2017). Low soil fertility, due to the average amount of N, P, K, S, and B in most Ethiopian soils, is a constraint to the production of potatoes at the national level. The production level of potatoes in the Angacha district is 51% of the total production in the Kembata Tembaro Zone (CSA 2013). The major production constraints that contributed to the production of potatoes are the lack of quality planting materials, the wrong management practices of soil that lead to low fertility of the soil, and the time of planting, which are the major and critical factors that limit the productivity of the potato crop (Dechassa et al., 2003).

Fertilizers that contain N, P, and K have been the only major inputs that have been influencing the yield and quality in the potato production practices (Bewket, 2019). The constant use of N, P, and K fertilizers in the national blanket recommendation is also another major problem in the district. Apart from the macronutrients, due to the longevity of potato production, some of the micronutrients, such as Zn and B, have been depleted from the soil (ATA, 2015). Thus, to maintain the fertility of the soil, the quantity and type of fertilizers used by crops and lost through leaching and other processes should at least be balanced through the use of necessary fertilizers (ATA, 2015). Therefore, the soil fertility in the study area is low and requires the use of fertilizers in potato production practices, which is not debatable.

However, the current application of fertilizer in the district for potato crop production is based on the practices of other regions, which are not similar to the agroecology in the study area. Furthermore, farmers in the area cultivate local potato varieties rather than improved varieties that yield low productivity. Since the potato varieties' reaction to the fertilizer rate is location and soil-type-dependent, the addition and application of K, B, S, and Zn in blended fertilizer for soils that are nutrient-deficient in such elements can enhance the efficiency of fertilizer application and profitability of crop production as well (EthioSIS, 2013).

Most of the Ethiopian soils, as well as soils in the Angacha district, are deficient in N, P, K, S, Zn, and B. Therefore, the research on the response of potato varieties to blended fertilizers under agro ecology, such as the Angacha district, is of paramount importance to ensure the maximum productivity of the potato crop and make recommendations. Therefore, this research was conducted with the general objective of determining the effects of different types of blended fertilizers on the productivity of potato (Solanum tuberosum L.) varieties and on soil physicochemical properties in the Angacha district.

2. Method and Materials

2.1. Description of the Study Site

The study was conducted at the Ambracho Wasera Farmers Training Center (FTC) in the Angacha District of Ethiopia's Kembata Tembaro Zone. This site, located at 7°03′ N latitude and 38°29′ E longitude at an elevation of 2381 meters above sea level, is characterized by a mean annual temperature ranging from 14°C to 24°C. It receives a bimodal average rainfall of 1656 mm, typically occurring from February to September, with peak precipitation recorded in April, July, August, and September (Angacha District Agriculture Office, 2019; National Meteorological Agency of Ethiopia, 2022).

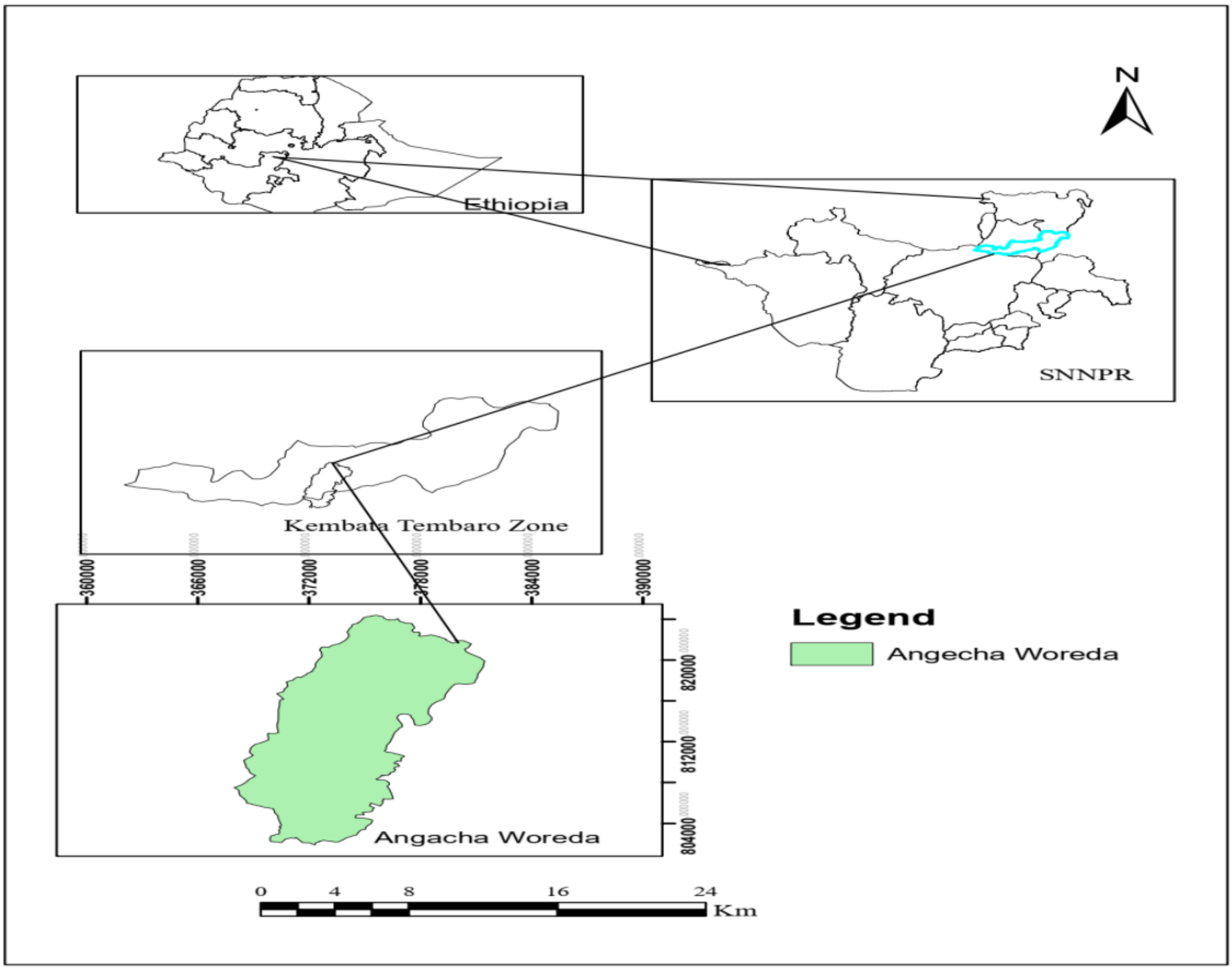

Figure 1. *Map of the study area (Source: ADAO, 2019)*

2.2. Experimental Procedures and Materials

Soil samples were taken at a depth of 0-30 cm before planting and after harvest using an auger drill. Potato varieties that are commonly adapted to the region were used as planting materials, while fertilizer varieties included Urea, DAP, NPS blended fertilizers, boron, zinc sulfate, and potassium sources as recommended in previous studies on blended fertilizers (Table 1) (Yohannes & Zebire, 2024; Bekele, 2024; Semman et al., 2023; Temesgen & Getachew, 2023).

2.3. Treatments and Experimental Design

The design of the experiment consisted of a completely randomized block design and a factorial treatment arrangement. There were 3 types of potato varieties and 5 types of blended fertilizer formulations to produce a total of 15 treatment combinations (3 potato varieties × 5 fertilizer formulas = 15). There were a total of 45 experimental plots (3 replications x 15 treatment combinations = 45) for this study (Gomez & Gomez, 1984; Steel et al., 1997). The treatment combinations can be found in Table 1.

The size of each experimental plot was 3.75 m × 3.3 m, giving a total area of 12.375 m². For each plot, five rows were laid out, with 11 plants in each row. The row-to-row distance was 75 cm, and the plant-to-plant distance in a row was 30 cm. A distance of 1 m was kept between plots, and a distance of 1.5 m was kept between blocks to enable easy field work and to avoid any interference between plots. The dimensions of the plots, plant spacing, and alley width were standardized according to the recommended guidelines for potato field experimentation (Singh & Singh, 2005; Kumar & Singh, 2018).

Table 1. *Treatment combinations of fertilizers and potato varieties*

Treatments	Fertilizers (kg ha^{-1})	Potato varieties
T1	Control (No fertilizer)	Gudenie
T2	Control (No fertilizer)	Digemagn
T3	Control (No fertilizer)	Beletach
T4	100 kg DAP+ 200 kg Urea	Gudenie
T5	100 kg DAP+ 200 kg Urea	Digemagn
T6	100 kg DAP+ 200 kg Urea	Beletach
T7	100 kg NPS+200 kg Urea	Gudenie
T8	100 kg NPS+200 kg Urea	Digemagn
T9	100 kg NPS+200 kg Urea	Beletach
T10	100 kg NPKSB+200 kg Urea	Gudenie
T11	100 kg NPKSB+200 kg Urea	Digemagn
T12	100 kg NPKSB+200 kg Urea	Beletach
T13	150 kg NPKSBZn+200 kg Urea	Gudenie
T14	150 kg NPKSBZn+200 kg Urea	Digemagn
T15	150 kg NPKSBZn+200 kg Urea	Beletach

2.4. Agronomic Practices and Methods of Fertilizer Application

Field preparation was done following conventional agronomic practices for potato cultivation, such as adequate land tillage, seedbed preparation, and the use of well-sprouted, medium-sized tubers (Gebrehawariat et al., 2020; Mengesha et al., 2024). All normal agronomic practices, including weeding, hilling, and irrigation, were done at the correct growth stages to facilitate the proper development of roots, stolons, and tubers.

Fertilizer application was done based on conventional nutrient management practices for potato in Ethiopia (Legese, 2023). The total amount of mixed fertilizer was applied at planting time, placed in rows alongside the seed tubers. Urea fertilizer, however, was applied in split applications, with half applied at planting time and the rest as a side dressing at tuber initiation. Split application of fertilizer is a practice that improves the efficiency of nitrogen fertilizer use by matching the availability of nutrients with crop requirements, thus avoiding the risk of potential losses of fertilizer nitrogen through leaching and volatilization (Gebrehawariat et al., 2020; Hailu & Aga, 2019). All agronomic practices were done at the right time during the growing season to promote proper crop establishment and maximize yield potential.

2.5. Soil Sampling Procedures and Analysis

Before planting, soil cores were collected randomly from the experimental field to a depth of 30 cm using an auger. These subsamples were then combined to create a single, homogeneous composite sample weighing approximately 1 kg. Following the harvest, separate soil samples were obtained from each plot. In the laboratory, all collected samples were prepared by air-drying, grinding, and passing them through a 2 mm sieve. Subsequent analysis for selected physical and chemical properties adhered to established laboratory protocols. Specifically, the

Bouyoucos hydrometer method (Bouyoucos, 1962) was employed for texture determination. Organic carbon (OC) and total nitrogen (N) were quantified using the Walkley-Black oxidation method (Walkley and Black, 1934) and the Kjeldahl procedure (Dewis and Freitas, 1975), respectively. A digital pH meter was used to measure soil pH in a 1:2.5 soil-to-water suspension (Page, 1982). For nutrient analysis, available phosphorus (P) was extracted following Olsen et al. (1954), while available sulfur (S) was determined by the 0.01M $Ca(H_2PO_4)_2$ turbidimetric method (Hoeft et al., 1973). Cation exchange capacity (CEC) was assessed through saturation with 1N ammonium acetate (NH_4OAc) followed by displacement with 1N sodium acetate (NaOAc) (Landon, 1991). The resulting extracts were also used to measure available potassium (K) via flame photometry (Rowell, 1994). Finally, available boron (B) and zinc (Zn) were estimated using the hot water method (Havlin et al., 1999) and the AAAc-EDTA extraction method (Cottenie, 1980), respectively.

2.6. Crop Data Collection

2.6.1. Phenological Data Collection

Days to flowering: Measured as the number of days from planting to the stage when 50% of the plants in each plot had produced at least one open flower.

Days to physiological maturity: Measured as the number of days from planting to the stage when 50% of the plant population had senesced haulms (vines), as indicated by yellowing and drying of the foliage (Temesgen & Getachew, 2023; Hussen, 2022).

2.6.2. Growth and Yield Parameters Data Collection

Plant height (cm): Recorded six weeks after emergence from the base of the plant to the tip of the tallest leaf using a measuring tape (Bekele, 2024).

Number of marketable tubers (t ha^{-1}): Recorded as healthy, undamaged tubers that are free from deformities, rotting, greening, or undersized, suitable for market or consumption.

Number of unmarketable tubers (t ha^{-1}): Recorded as tubers that were rotten, green, diseased, insect-damaged, or undersized, making them unsuitable for market (Semman et al., 2023).

Specific gravity of tubers: Measured using the weight in air minus weight in water method, calculated as: Specific Gravity = weight in air / (weight in air- weight in water).

Number of tubers per hill: The number of tubers per hill was measured by counting the total number of tubers harvested from sampled plants in each plot and was reported as the average number of tubers per hill (Abate, Tesfaye, & Lemma, 2023; Hussen, 2022).

Total tuber yield (t ha^{-1}): Calculated as the sum of marketable and unmarketable tuber yields per plot, subsequently converted to tons per hectare (Yohannes & Zebire, 2024).

Harvest index (%): Calculated as the ratio of tuber fresh weight to total above-ground biomass fresh weight at harvest, expressed as a percentage (Hussen, 2022).

2.7. Statistical Analysis

Statistical analysis was performed using SAS software (version 9.3, SAS Institute Inc., Cary, NC, USA). A two-way analysis of variance (ANOVA) was conducted using the General Linear Model (GLM) procedure to evaluate the main effects of variety and blended fertilizer rates, as well as their interaction, on the measured parameters. When the ANOVA indicated significant differences ($P < 0.05$), treatment means were compared using Fisher's Least Significant Difference (LSD) test.

3. Results and Discussion

3.1. Pre-planting and Post-harvest Soil Physicochemical Properties

The use of blended fertilizer contributed significantly to the improvement of the nutritional status of the experimental soil. The physicochemical characteristics were measured before the crop was planted and after the harvest of the crop to determine the effects of the treatment (Table 2). The soil texture type was silty clay loam before the application of fertilizer and after harvest. This indicates that soil texture is a natural property of the soil that is not affected by fertilizer management practices. The soil texture type is ideal for potato (*Solanum tuberosum L.*) growth, as the crop grows best in well-drained loamy soils that support root and tuber development (Brady and Weil, 2002). The pH levels of the soil were measured at 6.10 before planting and 5.90 after harvest. The soil was slightly to moderately acidic, as classified by Tekalign (1991). The pH levels of the soil are within the acceptable limits for agricultural soils and support the availability of nutrients for potato growth.

The organic carbon (OC) content in the soil was relatively unchanged, ranging from 1.83% before planting to 1.78% after harvest. Likewise, the total nitrogen (N) content was reduced slightly from 0.15% to 0.13% during the cropping season (Table 2). According to Tekalign (1991), both soil OC and total N contents were considered moderate. The fact that total N content was reduced after harvest indicates that the potato crop is actively taking up nutrients, and thus additional N fertilization is required to maintain optimal tuber yield potential. Available phosphorus (P) content was determined to be 4.96 mg kg^{-1} before planting and 4.91 mg kg^{-1} after harvest (Table 2). These levels are considered very low based on fertility standards (Tekalign, 1991; Olsen et al., 1954). The low available P level is insufficient to support optimal potato growth and tuber yield, thus emphasizing the importance of P supplementation through the use of blended fertilizers in the study area.

Table 2. *Selected soil physicochemical properties of soils of the experimental site*

Soil analysis	Particle size distribution (%)										
	Sand	Silt	Clay	pH	OC (%)	Total N (%)	Av. P (mg kg^{-1})	Av. K (mg kg^{-1})	Av. S (mg kg^{-1})	Av. B (mg kg^{-1})	CEC cmol(+)kg^{-1}
Before planting	25	41	34	6.10	1.83	0.15	4.96	0.60	24.40	0.40	20.22
After harvesting	26	40	34	5.90	1.78	0.13	4.91	1.20	21.30	0.46	22.12

The respective content of available K was 0.60 mg kg-1 and 1.2 mg kg-1 before and post-harvest and was rated as medium to high (FAO, 2006). The available sulfur of the soil was 24.00 mg kg-1 before planting and 24.8 mg kg-1 after harvesting, and was rated as medium in available sulfur, which is unsatisfactory for optimal potato growth and production. The mean B value of the soil was 0.4 mg kg-1 before planting and 0.46 mg kg-1 post-harvest, and was rated as deficient EthioSIS (2013) that the use of B fertilizer. The CEC of soil was 20.22 cmol (+) kg-1 and 22.12 cmol (+) kg-1 soil before planting and after harvesting, respectively, indicating its medium capacity to retain cations (Landon, 1991) (Table 2).

3.2. Effect of Blended Fertilizer on Phenological and Growth Parameters of Potato Varieties

3.2.1. Days to 50% flowering

Analysis of variance showed that days to 50% flowering were significantly affected by variety and NPKSZnB fertilizer rates, and their interaction was non-significant (Table 3). Phenological stages, especially flowering, are important indicators of crop adaptation and maturity in potato production systems. Recent transcriptomic analyses have shown that flowering time in potatoes is closely associated with tuberization processes mediated by complex molecular regulatory networks involving major genes StSP6A and StCDF1 (Brose et al., 2025; Li et al., 2025). There was significant variation in days to 50% flowering among the potato varieties tested (Table 3). The Gudenie variety had the earliest flowering, which reached 50% anthesis at 46.61 days after planting. However, the Beletech variety showed the longest vegetative growth period, taking 54.14 days to reach 50% flowering. The Digemagn variety had an intermediate flowering period (48.57 days).

These genotypic variations in flowering times can be explained by the natural genetic constitution and capability of the varieties to perform physiological functions. Recent studies by Li et al. (2025) among early-maturing (KX23) and late-maturing (DN310) potato varieties showed that the difference in maturity is associated with the timing of tuberization processes, where flowering in aboveground stems occurs when the cessation of stolon elongation takes place, marking the beginning of tuberization. Early flowering varieties such as Gudenie may have genetic factors that promote early flowering by virtue of differential expression of key regulatory genes associated with the transition from vegetative to reproductive growth phases (Brose et al., 2025; Lee & Kim, 2025). The results show that the varieties have differences in flowering times, which are consistent with the results reported by Mekides et al. (2020), where the Beletech variety took 69.17 days to attain 50% flowering, which is about 4 days longer than the local checks. Similar genotypic variations in flowering responses have also been reported among potato varieties grown under different agro-ecological settings, where studies by Çalışkan et al. (2024) showed significant differences in 50% flowering times among the varieties tested in nematicide-treated and nematode-infested fields.

The application of NPKSZnB blended fertilizer had a significant effect on the days to 50% flowering, with a noticeable trend of delayed flowering as the fertilizer rate increased (Table 3). The control treatment, which received no fertilizer, took 60.33 days to reach 50% flowering, while the longest period took 67.55 days for the highest fertilizer rate treatment of 150 kg NPKSZnB + 200 kg urea ha^{-1}, which was a delay of about 7 days from the control treatment. The progressive delay in flowering with the increasing application rate of fertilizer is most likely due to the nitrogen (N) content of the blended fertilizer. Nitrogen has long been recognized as a fertilizer nutrient that accelerates vegetative growth and prolongs the vegetative phase of many crops, including potatoes (Marschner, 2012). In recent studies conducted by Su et al. (2024) on water-nitrogen regulation in cold and arid regions, it was found that tuber yield, dry matter accumulation, and plant height were all increased with the increasing application rate of nitrogen fertilizer, with the medium application rate of 185 kg ha^{-1} of nitrogen fertilizer combined with mild water deficit stress yielding optimal results.

The lack of significant interaction between cultivar × fertilizer rate for the number of days to 50% flowering suggests that fertilizer application produces a uniform phenological response across all varieties tested. In other words, while there is inherent variation among cultivars in terms of their time to flower, the corresponding relative delay due to increased fertilizer application will follow a similar trend across genotypes; thus, all types of varieties will experience similar relative flowering delays due to higher fertilizer rates. Breakthroughs in the molecular mechanisms underlying potato flowering have recently led researchers to identify several candidate genes (e.g., StBEL5, StSP6A, and StCDF1) that are associated with tuber induction and development in all potato varieties (Brose et al., 2025; Li et al., 2025). Therefore, optimal fertilizer management strategies are necessary to maximize yield and quality in potato production systems by leveraging the vegetative and reproductive growth phases (Su et al., 2024; Zhong et al., 2025).

3.2.2. Days to 90% physiological maturity

Physiological maturity, which is the stage at which 90% of the plants in a field have undergone senescence of the vines and skin set of the tubers, is an important phenological factor that determines the time of harvest and affects tuber quality and storage. Analysis of variance showed that the number of days to 90% physiological maturity was significantly ($p < 0.05$) affected by potato variety and the application rate of NPKSZnB blended fertilizer, whereas the interaction effect was non-significant (Table 3). Significant variation in the number of days to 90% physiological maturity was found among the tested potato varieties (Table 3). The Gudenie variety had the shortest maturation period, reaching 90% physiological maturity at 103.73 days after planting. The Beletech variety had the longest maturation period, taking 116.46 days to reach 90% physiological maturity, which was about 13 days longer than the shortest maturing Gudenie variety. The Digemagn variety had an intermediate maturation period of 110.30 days.

It is believed that Beletech's prolonged vegetative growth period is due to genetic characteristics that enable the plants to remain in the vegetative state for a long time and delay their eventual death. The late-maturing types of potato tend to spend more time building their leaf canopy and a secondary bulking of tuber mass, as long as the growing conditions are conducive to the accumulation of biomass (Li et al., 20025). The differences in maturation duration have been widely recognized across potato varieties, with research by Çalışkan et al. (2024) reporting that the difference in maturation time between varieties grown under similar conditions ranged from 10 to 15 days. Recent molecular biology studies have been undertaken using transcriptomic analysis to study differences in maturation times among potatoes. According to the published studies by Li et al. (2025), the difference in the maturation times of potato types is reflected by the differences in expression of key genes in the photoperiod pathway, and genes regulating tuber induction are known to be StSP6A and StCDF1, which are responsible for the transition from vegetative plant to potato tuber and also senescence. The delays in maturity observed with Beletech reflect the allelic variations of these major genes, resulting in a delayed vegetative growth period (Brose et al., 2025).

The application of NPKSZnB blended fertilizer significantly affected the time required to reach 90% physiological maturity, with a clear trend toward delayed maturity with increasing fertilizer rates (Table 3). The control treatment, which received no fertilizer, attained 90% physiological maturity at 103.72 days, which was the earliest maturity among the fertilizer treatments. The highest fertilizer rate treatment (150 kg NPKSZnB + 200 kg urea ha^{-1}) had the longest growth cycle, taking 117.53 days to attain 90% physiological maturity, which was a postponement of maturity by about 14 days compared to the control treatment. The postponement of maturity with increasing fertilizer rates is mainly due to the nitrogen (N) content in the blended fertilizer. Nitrogen is known to promote vegetative growth and postpone senescence in various crop species, including potato (Marschner, 2012). Increased nitrogen availability promotes prolonged photosynthesis and extended greenness of the canopy, hence extending the bulking phase of the tubers and postponing the onset of physiological maturity (Su et al., 2024).

The recorded delay in maturation due to fertilizer application is consistent with the results presented by Kinde and Asfaw (2016), who found that the increased application rate of blended fertilizer resulted in the excessive prolongation of days to physiological maturity in potato. Such trends have also been observed in recent studies on nitrogen management in potato production systems. Su et al. (2024) showed that the increased application of nitrogen from 0 to 185 kg ha^{-1} resulted in the progressive delay of plant senescence and the extension of the crop growth cycle in cold and arid conditions. Zhong et al. (2025) further confirmed these trends using UAV-based remote sensing, which showed that the development duration of the canopy systematically increased with the nitrogen application rate, and the integral area under the canopy development curve at peak flowering was significantly correlated with the final yield.

Table 3. *Mean values of 50% flowering and 90% physiological maturity as influenced by potato varieties and blended fertilizer application*

Main effect	50% of Flowering	90% Physiological maturity
Variety		
Gudenie	46.61^{b}	103.73^{c}
Digemagn	48.57^{b}	110.30^{b}
Beletech	54.14^{a}	116.46^{a}
LSD (0.05%)	2.04	1.14
Blended fertilizer (kg ha^{-1})		
0 (Control)	46.30^{d}	107.72^{e}
100 DAP + 200 Urea	47.16^{cd}	106.22^{d}
100 NPS + 200 Urea	49.27^{bc}	110.16^{c}
100NPKSB + 200 Urea	51.66^{ab}	113.16^{b}
150NPKSZnB + 200 Urea	53.55^{a}	117.53^{a}
LSD (0.05)	2.63	1.47
CV (%)	4.29	1.38

Means in the column tailed by the similar letter(s) are insignificantly different at $P < 0.05$; LSD= Least Significant Difference.

3.3. Plant Height

Plant height, an important vegetative growth indicator, was significantly ($p < 0.05$) affected by variety, NPKSZnB fertilizer rates, and their interaction (Table 4). This shows that the response of varieties to fertilizer application was not similar across treatment levels. As the fertilizer rate was successively raised from 0 to 150 kg NPKSZnB + 200 kg urea ha^{-1}, plant height increased in all varieties, with the maximum response in Gudenie, which grew from 43.86 cm (control) to 88.06 cm (maximum rate)—a 101% increase. The lowest plants (43.86 cm) were measured in the control treatment for Gudenie and Digemagn varieties. The positive height response to increased fertilizer rates can be ascribed to the nitrogen-stimulated cell division and elongation, together with phosphorus-stimulated root growth and nutrient uptake (Marschner, 2012). These results are in agreement with Alemayehu et al. (2015), who found significant plant height increments with increasing nitrogen application in potato. Similar results were obtained by Bewket (2019), who observed that increased N and P application rates stimulated vegetative growth, leaf expansion, and stem elongation, supporting the current results.

Table 4. *Interaction effect of varieties and blended fertilizer on potato plant height*

	Plant height (cm)				
	Blended fertilizer rates (kg ha^{-1})				
Variety	0 (Control)	100DAP +200 Urea	100NPS+200 Urea	100NPKSB+200 Urea	150 NPKSZnB + 200 Urea
Gudenie	43.86^{h}	59.53^{f}	74.33^{d}	78.26^{c}	88.06^{a}
Digemagn	43.86^{h}	68.00^{e}	74.60^{d}	78.10^{c}	83.40^{b}
Beletech	48.06^{g}	66.20^{e}	76.88^{cd}	79.30^{c}	83.3^{b}
LSD (0.05)		2.93			
CV (%)		2.51			

Means in the column tailed by the similar letter(s) are insignificantly different at $P < 0.05$; LSD= Least Significant Difference.

3.4. Yield and Yield Components of Potato as Influenced by Blended Fertilizer and Varieties

3.4.1. Marketable tuber yield (t ha-1)

Marketable tuber yield, an important factor in the economic efficiency of potato crop production, was significantly ($p < 0.05$) affected by variety, NPKSZnB fertilizer rates, and their interaction (Table 6), showing the varying sensitivity of potato varieties to fertilizer application. Marketable tuber yield of 46.63 t ha^{-1} was obtained for Gudenie at the highest fertilizer rate of 150 kg NPKSZnB + 200 kg urea fertilizer ha^{-1}, which is a 154% increase over the control receiving no fertilizer. In contrast, the yield of Digemagn and Beletech varieties was 41.06 and 35.49 t ha^{-1}, respectively, at the same fertilizer rate. The lowest marketable tuber yield of 18.35 t ha^{-1} was realized from Beletech in the control treatment. The better yield response of Gudenie indicates its higher genetic potential to utilize the applied fertilizer for tuber yield. Tulu et al. (2025) also found that the Belete variety responded better to fertilizer application, realizing a 279.5% increase in marketable tuber yield with 250 kg ha^{-1} NPSB fertilizer compared to the control without fertilizer in the Walmara District of Ethiopia, thus establishing the existence of large varietal differences in fertilizer response.

The increased marketable yields with higher NPKSZnB application rates can be attributed to better nutrient supply, especially nitrogen and phosphorus, which induce tuber formation, bulking, and improvement (Marschner, 2012). A meta-analysis conducted by Liao et al. (2025) showed that optimal fertilizer application (150-250 kg N ha^{-1}, combined with balanced P and K applications) greatly improved potato water productivity and marketable yields, especially when using drip irrigation. The 154% yield increase in this study is much higher than the 55% average increase in supplementary irrigation yields worldwide (Liao et al., 2025), indicating the synergistic effect of proper fertilization and suitable growing conditions. The physiological explanation for the increased yield with optimal fertilization is complex and involves several processes. Tarchoun et al. (2025) showed that optimal NPK application rates increased chlorophyll fluorescence parameters and photosynthetic efficiency, directly leading to increased tuber yields, with the mid-early variety 'Spunta' reaching maximum yield (615.4 g plant^{-1}) with optimal fertilization. Similarly, Zhong et al. (2025) used combined transcriptomic and metabolomic analyses to show that optimal basal fertilizer application rates increased the expression of key genes involved in starch biosynthesis and anthocyanin accumulation, providing molecular evidence for fertilizer-induced yield enhancement.

Nitrogen management is also a very important aspect. Li et al. (2025) reported that appropriate nitrogen management (200 kg ha⁻¹) along with optimal plant density (52,500 plants ha⁻¹) resulted in a substantial increase in the activity of key enzymes involved in carbon-nitrogen metabolism (Rubisco, GS, GOGAT, and AGPase), resulting in improved starch accumulation and tuber yield. The study showed that the activity of AGPase was increased by 7.85-31.17% due to integrated management, which directly contributed to improved starch synthesis during tuber bulking. The variety × fertilizer interaction, which was significant in this study, is supported by the Colorado State University study, where variety-specific responses to nitrogen and irrigation management were established. Specifically, Russet Norkotah3 showed yield reduction with 16-23% irrigation cutbacks, whereas Canela Russet, Mesa Russet, and Yukon Gold showed similar yields with ≤18% irrigation reduction (Colorado State University, 2025). This further emphasizes the need for variety-specific fertilizer recommendations. The significance of the interaction again emphasizes the need for variety-specific fertilizer recommendations. With the global potato production reaching a record high of 383 million tons in 2023 (Food and Agriculture Organization [FAO], 2024), with Asia contributing about 54% of the total production, fertilizer management practices remain important for sustainable intensification.

Table 5. *Interaction effect of varieties and blended fertilizer on marketable tuber yield of potato*

	Marketable tuber yield (t ha^{-1})				
	Blended fertilizer rates (kg ha^{-1})				
Variety	0 (Control)	100 DAP + 200 Urea	100NPS+200 Urea	100NPKSB+200 Urea	150 NPKSZnB+200 Urea
Gudenie	22.44^{j}	33.71^{ef}	37.12^{cd}	40.77^{b}	46.63^{a}
Digemagn	20.04^{j}	27.77^{h}	34.24^{e}	35.41^{de}	41.06^{b}
Beletech	18.35^{j}	24.29^{i}	31.02^{g}	31.87^{fg}	35.39^{c}
LSD (0.05)	2.02				
CV (%)	3.76				

Means in the column tailed by the similar letter(s) are insignificantly different at P < 0.05; LSD= Least Significant Difference.

3.4.2. Total tuber yield (t ha-1)

Total tuber yield was significantly ($p < 0.05$) affected by variety, NPKSZnB fertilizer application rates, and their interaction (Table 7). Gudenie had the highest total tuber yield (48.85 t ha⁻¹) at the highest fertilizer application rate (150 kg NPKSZnB fertilizer + 200 kg urea fertilizer per ha), performing better than Digemagn (43.35 t ha⁻¹) and Beletech (40.75 t ha⁻¹) by 11.3% and 16.6%, respectively. The lowest total tuber yield (19.73 t ha⁻¹) was obtained by Beletech in the unfertilized control treatment, which was 59.6% lower than the fertilized treatment.

The better performance of Gudenie is indicative of higher genetic potential for nutrient uptake and allocation to tubers, as supported by recent evidence on cultivar differences in nitrogen use efficiency (Li et al., 2025; Tarchoun et al., 2025). The use of fertilizer resulted in a yield increase of 21.0-29.1 t ha⁻¹, which is in line with Getie et al. (2015) and the average yield increase of 55% reported in the global meta-analysis (Liao et al., 2025). The interaction effect emphasizes the importance of fertilizer use recommendations for specific varieties. The yield obtained (48.85 t ha⁻¹) is well above the global (21 t ha⁻¹) and Ethiopian (13-15 t ha⁻¹) averages (FAO, 2024), indicating large yield gaps that can be filled by proper management.

Table 6. *The interaction effect of Blended fertilizer and varieties on Total tuber yield of potato*

Total tuber yield (t ha^{-1})					
	Blended fertilizer rates (kg ha^{-1})				
Variety	0 (Control)	100 DAP + 200 Urea	100NPS + 200 Urea	100NPKSB + 200 Urea	150 NPKSZnB + 200 Urea
Gudenie	23.73^{j}	35.02^{f}	38.66^{d}	42.86^{b}	48.85^{a}
Digemagn	21.50^{k}	29.34^{h}	35.88^{ef}	37.60^{de}	43.35^{b}
Beletech	19.73^{k}	25.79^{i}	32.60^{g}	34.03^{fg}	40.75^{c}
LSD (0.05)		2.05			
CV (%)		3.62			

Means in the column tailed by the similar letter(s) are insignificantly different at $P < 0.05$; LSD= Least Significant Difference.

3.4.3. Tuber number per hill

Number of tubers per hill, an important component of yield, was significantly ($p < 0.05$) affected by variety, levels of NPKSZnB fertilizer, and their interaction (Table 8), which showed variation in varietal response to fertilizer application. Gudenie yielded the highest number of tubers (44.33 tubers hill^{-1}) when the highest fertilizer dose (150 kg NPKSZnB + 200 kg urea ha^{-1}) was applied, which was significantly higher (5.0% and 8.1%) than Digemagn (42.23) and Beletech (41.00), respectively. Digemagn outyielded Beletech at all fertilizer levels, indicating its superior genetic potential for tuber production. The steady rise in tuber number with fertilizer application (28-44 tubers hill^{-1}) can be ascribed to the presence of micronutrients (S, Zn, and B) in the NPKSZnB fertilizer blend. These micronutrients work together to increase nitrogen and phosphorus assimilation, cell division, chlorophyll content, and photosynthetic efficiency, thereby increasing tuber formation and retention (Masrie et al., 2015; Marschner, 2012). The interaction was significant, which highlights the importance of proper fertilizer management based on varietal tuberization response for maximum yield.

Table 7. *Interaction effect of Blended fertilizer and Potato varieties on tuber number per hill*

Tuber number per hill (count.)					
	Blended fertilizer rates (kg ha^{-1})				
Variety	0 (Control)	100 DAP+200 Urea	100NPS+200 Urea	100NPKSB+200 Urea	150 NPKSZnB+200 Urea
Gudenie	23.00^{h}	28.00^{g}	34.33^{de}	41.00^{b}	44.33^{a}
Digemagn	21.66^{hi}	29.00^{fg}	32.66^{e}	37.60^{c}	42. 23^{ab}
Beletech	20.00^{i}	30.23^{f}	35.00^{d}	38.00^{c}	41.00^{b}
LSD (0.05)		2.27			
CV (%)		4.08			

Means in the column tailed by the similar letter(s) are insignificantly different at $P < 0.05$; LSD= Least Significant Difference.

3.5. Effect of Blended fertilizer and Varieties on Unmarketable tuber yield, Specific gravity of tuber, and Harvest index

3.5.1. Unmarketable tuber yield (t ha-1)

Unmarketable tuber yield was significantly ($p < 0.05$) affected by variety and NPKSZnB fertilizer rates, but not their interaction, which was non-significant (Table 10). Beletech had the lowest unmarketable tuber yield (1.69 t ha^{-1}), slightly lower than Gudenie (1.83 t ha^{-1}), a 7.7% reduction. This indicates that Beletech may have better tuber uniformity or less vulnerability to damage under the given conditions. Similar varietal differences in unmarketable tuber yield have been reported, with Beletech variety having a lower unmarketable tuber yield than Gudane in a mixed fertilizer experiment at Assosa (Bekele, 2024). Fertilizer application increased unmarketable tuber yield with an increase in fertilizer rate. The control had the lowest unmarketable tuber yield (1.37 t ha^{-1}), while the highest fertilizer rate (150 kg NPKSZnB + 200 kg urea ha^{-1}) resulted in the highest unmarketable tuber yield (2.25 t ha^{-1}), a 64% increase. This trend may be attributed to the increased overall tuber yield, where some of the additional tubers may not attain marketable size and quality. Ejerso et al. (2024) also found that the combined use of vermicompost and NPSZnB had a significant effect on unmarketable tuber yield, where higher rates of fertilizer use tended to increase unmarketable tubers. Alemayehu and Jemberie (2018) also found that although fertilizer use increased total and marketable tuber yields, it may also result in the increased production of unmarketable tubers because of increased tuber formation and competition for assimilates. Solomon et al. (2019) further indicated that the application of inorganic fertilizers (N, P, and S) had a significant effect on marketable tuber yield components, which may have implications for unmarketable tubers. The lack of significant interaction terms makes it easier to manage the effect of fertilizers on unmarketable tuber yields.

Table 8. *The main effect of blended fertilizer and varieties on unmarketable tuber yield, specific gravity and harvest index*

Main effect	Unmarketable tuber yield (t ha^{-1})	Specific gravity	Harvest index (%)
Variety			
Gudenie	1.83[a]	1.151[a]	67.5[a]
Digemagn	1.77[b]	1.077[b]	65.2[c]
Beletech	1.69[c]	1.075[b]	65.3[b]
LSD (0.05)	0.04	0.018	0.9
Blended fertilizer (kg ha^{-1})			
0 (Control)	1.37[e]	1.127[a]	64.2[c]
100 DAP + 200 Urea	1.46[d]	1.111[ab]	65.1[c]
100 NPS + 200 Urea	1.59[c]	1.098[bc]	65.2[c]
100NPKSB + 200 Urea	2.14[b]	1.090[bc]	67.0[b]
150NPKSZnB + 200 Urea	2.25[a]	1.079[c]	68.6[a]
LSD (0.05)	0.06	0.023	1.1
CV (%)	13.56	2.21	1.38

Means in the column tailed by the similar letter(s) are insignificantly different at P < 0.05; LSD= Least Significant Difference.

3.5.2. Specific gravity of tubers

Tuber specific gravity, a quality parameter of considerable importance, is a measure of dry matter content and processing quality. It was significantly ($p < 0.05$) affected by variety and NPKSZnB fertilizer rates, but the interaction was non-significant (Table 9;).Gudenie had the highest specific gravity value of 1.75, indicating better dry matter accumulation ability than other varieties. Varietal differences exist due to genetic differences in carbohydrate partitioning and starch synthesis ability (Li et al., 2025). Fertilizer application resulted in a progressive decrease in specific gravity with an increase in fertilizer rates. The control (no fertilizer) had the highest specific gravity value of 1.127, while the highest fertilizer rate of 150 kg NPKSZnB + 200 kg urea ha^{-1} gave the lowest value of 1.079, a decrease of 4.3%.

This negative relationship between fertilizer dose and specific gravity can be ascribed to the nitrogen-induced changes in carbohydrate partitioning. Higher nitrogen availability enhances vegetative growth and water accumulation in tubers at the expense of dry matter production, thus diluting the starch concentration and specific gravity (Marschner, 2012). These results are in agreement with Mekides et al. (2020), who observed that nitrogen and phosphorus application resulted in decreased specific gravity of potato tubers. Similar results were observed by Tarchoun et al. (2025), who noted that higher nitrogen application resulted in decreased dry matter content and specific gravity of various potato varieties. The lack of significant interaction suggests that the inhibitory action of nitrogen on specific gravity is uniform across varieties, but the initial level is genetically different.

3.5.3. Harvest index

Harvest index (HI), which is a measure of the efficiency of biomass allocation to economic yield, was significantly ($p < 0.05$) affected by variety and rates of NPKSZnB fertilizer application, but their interaction was non-significant. Gudenie had the highest HI (67.5%), which was higher than Digemagn (65.2%) and Beletech (65.3%) by about 2.3 percentage points. This shows better physiological efficiency in allocating assimilates to tubers rather than vegetative parts, which is desirable in modern high-yielding varieties (Li et al., 2025).

Fertilizer application rate significantly increased HI. The highest HI (68.6%) was obtained at the highest fertilizer application rate of 150 kg NPKSZnB + 200 kg urea ha^{-1}, while the lowest HI (64.2%) was obtained in the control treatment, which was 4.4 percentage points higher (Table 9).

This fertilizer-induced HI increase is a result of improved nutrient availability, which in turn increases the efficiency of photosynthate partitioning to tubers (economic yield) over total biomass. Nitrogen and phosphorus work together in improving source-sink ratios, making it efficient for carbohydrates to be transported to tubers (Marschner, 2012). These results are in agreement with Garo et al. (2014), who found that high carbon assimilating producers retain high HI values under fertilizer application regardless of the total biomass produced. The non-significant interaction term shows that the effect of fertilizer on the efficiency of partitioning is consistent across genotypes, although the initial HI values are genetically different.

4. Discussion

This research showed that the interaction of NPKSZnB mixed fertilizer and potato variety had a significant effect on phenology, yield attributes, and overall productivity, thus emphasizing the need for genotype-specific nutrient management. Gudenie showed better performance, with the highest total tuber yield (48.85 t ha^{-1}), marketable yield (46.63 t ha^{-1}), and tuber number per hill (44.33) when treated with 150 kg NPKSZnB + 200 kg urea ha^{-1}, which was

154%, 154%, and 58% higher than the control, respectively. Beletech and Digemagn showed 11.3-16.6% lower yields under the same fertilization regime, thus indicating substantial genetic variation in nutrient use efficiency. Fertilizer application gradually postponed phenological events while promoting growth and yield. Yet, higher unmarketable yield (1.37 to 2.25 t ha^{-1}) and lower specific gravity (1.127 to 1.079) indicate a compromise between maximizing productivity and maintaining quality. The harvest index increased from 62.4% to 68.6% with fertilization, with Gudenie showing better partitioning efficiency (67.5%).

5. Recommendations

To maximize yield, farmers are encouraged to plant the Gudenie variety with an application of 150 kg of NPKSZnB and 200 kg of urea per hectare. This combination has been shown to produce up to 48.85 tons per hectare, an impressive 3.5-fold increase over the national average. For those in the processing sector, where tuber dry matter content and specific gravity take precedence over total yield, a lower input rate of 100 kg NPKSZnB and 150 kg of urea per hectare is recommended. This approach balances quality with productivity. From a sustainability standpoint, this reduced dose still achieves 86% of the maximum yield while cutting fertilizer use by one-third, offering a resource-efficient alternative for environmentally conscious production. Lastly, Gudenie's strong responsiveness to nutrients positions it as valuable genetic material for breeders aiming to develop new varieties with improved nutrient use efficiency.

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Statement of Competing Interests

The authors declare that there is no conflict of interest.

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