**Original Research Article**

**Response of Tomato (*Solanum Lycopersicum* L.) Varieties to Application of NPS Fertilizer Rates in Gursum District, Somali Region, Ethiopia**

# ABSTRACT

*Tomato (Solanum lycopersicum) production in the Gursum District is crucial for both food supply and income generation, but it faces significant challenges such as soil nutrient deficiencies, limited access to improved varieties, and the need for optimal fertilizer application. These issues often lead to lower yields and reduced profitability for farmers. To address these challenges, an experiment was conducted to identify the best tomato variety and the optimal NPS fertilizer rate to maximize fruit yield and economic benefits. The study tested three tomato varieties (Cochoro, Chali, and Gelilema) and five NPS fertilizer rates (0, 50, 100, 150, and 200 kg ha⁻¹) using a randomized complete block design with three replications. The results showed that both the tomato variety and the NPS fertilizer rates significantly affected the days to 50% flowering and maturity, the number of fruits per cluster, the yield of marketable and unmarketable fruits, the total fruit yield, and the average fruit weight. However, the interaction between the variety and fertilizer rates was not significant. Higher NPS rates (200 and 150 kg ha⁻¹) led to increased days to flowering and maturity, improved plant growth, more fruit sets, and higher yields, with the highest values observed at 200 kg ha⁻¹. The control group had the lowest values for all parameters, highlighting the importance of NPS fertilizer. The 150 kg ha⁻¹ rate produced the highest marketable fruit yield (42.76 t ha⁻¹) and the best economic outcomes, including the highest net benefit (662,158 ETB), benefit-cost ratio (6.15), and marginal rate of return (5173.26%). Additionally, growing the Gelilema variety with 150 kg ha⁻¹ NPS fertilizer could further increase the net benefit, benefit-cost ratio, and marginal rate of return to 770,451 ETB, 7.16, and 5562.28, respectively. Therefore, applying NPS fertilizer rate of 150 kg ha⁻¹ and using Gelilema variety is recommended to optimize tomato production and profitability in the Gursum District.*

**Keywords**: Fertilizer, Marketable Fruit Yield, Net Benefit, Tomato, Variety

# INTRODUCTION

## Background and Justification

Tomato (Solanum lycopersicum L.) belongs to the Solanaceae family and the genus Solanum (Costa, 2018). It is believed to have originated in Ecuador and Peru, although the exact time and place of its domestication remain unknown with certainty (Blanca *et al*. 2022). The tomato is among the most economically significant vegetable crops. It ranks first worldwide among vegetables and is the fourth most economically important crop globally after rice, wheat, and soybean (Villareal, 2019). While the exact timing of the tomato's introduction to Ethiopia is unclear, the introduction of cultivated tomato into Ethiopian agriculture can be traced back to the period between 1935 and 1940 (Keskse *et al*. 2019). Today, it is one of the most popular and widely grown vegetables in the country.

Tomatoes are consumed fresh or in various processed forms. The major processed products include tomato preserves (whole peeled tomatoes, tomato juice, tomato pulp, tomato puree, tomato paste, and pickled tomatoes), dried tomatoes (tomato powder, tomato flakes, and dried tomato fruits), and tomato-based foods (tomato soup, tomato sauces, and ketchup) (Costa and Heuvelink, 2018). Tomatoes can play an important role in the human diet, providing essential nutrients such as calcium, iron, manganese, and particularly potassium (Lee *et al*., 2021). They also contain lycopene, a powerful antioxidant carotenoid that gives tomatoes their red color (Przybylska, 2020).

In Ethiopia, tomatoes are a popular vegetable grown by small farmers and commercial producers for fresh consumption and processing. They are used in various dishes, including salads and local sauces (Wot). Processed products like tomato paste, juice, and sauces are marketed widely. Tomatoes are a key cash crop for farmers and create jobs in production and processing (Glover and Kusterer, 2016). Even though tomatoes have great potential for high productivity in Ethiopia, the current productivity in the country is very low, even by African standards (Hunde 2017). Ethiopia is a major tomato producer in East Africa, with yields influenced by factors such as variety selection, irrigation practices, and pest management. Studies indicate that improved varieties and optimal irrigation significantly enhance yields. For instance, the Melkashola variety has shown high yields of 32.98 t/ha in North Shewa, while other varieties like Gelilema have demonstrated yields of 55.91 t/ha under irrigation (Fufa *et al*., 2025; Girma *et al*., 2023). Therefore, it is necessary to increase the productivity of the crop to strengthen the export potential and the growing tomato processing industries in the country (Naik and Suresh, 2018). The yield and quality of crops are influenced by many factors, including cultivars, planting materials and spacing, date of planting, soil and climate, types and rates of fertilizer application. Among several constraints. soil fertility is a major overriding constraint that affects all aspects of crop production (Zingore *et al.,* 2015). Therefore, many factors may contribute to the low yield of tomatoes in Ethiopia, but the low amount and types of fertilizers applied for production might contribute to the low production.

Low soil fertility is among the major problems constraining the productivity of tomato in Ethiopia (Biramo, 2018). Tomatoes are heavy feeders that need about 84 to 112 kg ha-1 of nitrogen and moderate to high levels of phosphorus (P) and potassium (K) for maximum yields (Bekele, Kibret *et al.,* 2018). The growth and yield of vegetable crops mainly depend on the quality and quantity of fertilizers used (Drobek *et al.,* 2019). In most of Ethiopia, there is no recommendation of fertilizer types and rates for tomato production specific to cultivars and locations, or agroecologies. It is common to apply the national recommendation of 92 and 46 kg ha-1 P2O5 and Nitrogen-containing fertilizers, respectively (Bekele *et al.,* 2019) at all locations and to all tomato varieties.

Despite the importance of tomato as a major horticultural crop in Ethiopia, its productivity remains significantly constrained by several interrelated factors, among which soil fertility and appropriate fertilizer management stand out as critical challenges. Tomatoes, being heavy feeders with long growing seasons, require not only adequate quantities of nutrients but also site- and cultivar-specific fertilizer recommendations to achieve optimal growth and yield. Although previous studies across various regions in Ethiopia have explored the impact of different organic and inorganic fertilizer combinations on tomato performance, there is a notable lack of research specific to the semi-arid agro-ecological conditions of Gursum woreda in the Fafan Zone, where a newly introduced blended NPS fertilizer (containing 19% N, 38% P₂O₅, and 7% S) is being promoted to replace traditional DAP fertilizers. Given that the nutrient uptake and use efficiency of tomato varieties vary significantly depending on environmental conditions, genetic makeup, and agronomic practices, it becomes essential to assess not only the independent but also the interactive effects of different tomato varieties and NPS fertilizer rates under local conditions. Furthermore, with growing interest in sustainable and economically viable agricultural practices, there is a pressing need to determine the economic feasibility of using blended fertilizers in tomato production in this specific context. This study, therefore, fills a critical gap by evaluating the phenological, growth, yield, and economic responses of tomato varieties to NPS fertilizer application under the unique semi-arid conditions of Gursum woreda, thereby contributing localized and practical recommendations for improving tomato productivity in the region.

# 3. MATERIALS AND METHODS

## 3.1. Description of Experimental Site

A field experiment was conducted in irrigated conditions, at Golhajo on a farmer’s vegetable farm from August 2022 up to November 2023. The site is found in Gursum Woreda, Fafan Zone of Somali Region, and eastern Ethiopia. It is located at 594 km from Addis Ababa to the East and 32 km from Jigjiga town to the west. *Golhajo* area is located at 9° 20’ N latitude and 45° 56’ E longitude, and has an elevation of 1,650 m.a.s.l. (Degefu *et al.,* 2011). The area receives an average annual rainfall of about 500-600 mm. The minimum temperature is around 10°C, with the maximum being 34°C (Mohamad, 2014).

The soil of the specific site is fertile and silt loam type; moreover, the climate is generally semiarid, as well as high saline content of underground water (MoARD, 2012). The major annual crops grown in the area, are cereals (sorghum and maize), oil crops (groundnuts), pulses (haricot bean and cowpea), vegetables (onion, garlic, and tomato), fruit crops (papaya, orange and mango) and ‘chats as perennial crop (Aklilu and Mekiso, 2015).

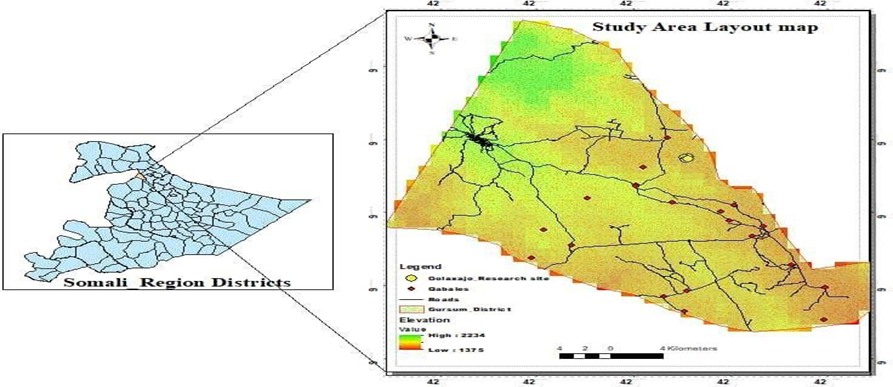


Figure . Geographical map of the study area

## 3.2. Description of Planting Materials

Three tomato varieties, Cochoro and Chali Gelilema, were used as planting materials. The Cochoro and Chali varieties were registered in 2007, while the Gelilema variety was registered in 2014. They are open-pollinated varieties released for lowland irrigated agroecology by the Melkassa Agricultural Research Center (MARC) under the Ethiopian Institute of Agriculture Research (MoA, 2020).

## 3.3. Treatments and Experimental Design

The treatments consisted of a factorial combination of five rates of blended NPS (0, 50, 100, 150, and 200 kg ha-1) and three tomato varieties (Cochoro, Chali, and Gelilema**)**. In addition, 100 kg ha-1 of Urea fertilizer was applied to all plots. The full rate of NPS fertilizer was applied at the time of transplanting, while Urea was applied in splits, half at the time of transplanting and half at 1½ months after transplanting with irrigation water. The experiment was laid out as a Randomized Complete Block Design (RCBD) with three replications. Each plot was 3.6 m long and 5 m wide, and had a gross plot area of 18 m2.Each plot consisted of five rows, each row accommodating 12 plants, and 60 plants per plot. Of which 36 plants in the central row, exclusive of plants at both ends of each row of each plot, were used for yield and yield-related data collection. Inter-row spacing of 1 m and intra-row spacing of 0.3 m was maintained, and the spacing of 1m and 1.5 m was maintained between plots and replications, respectively.

## 3.4. Experimental Procedure and Field Management

Seedlings were raised on a seedbed in the nursery close to the experimental field for one month. Weeds and stubbles was removed and the soil pulverized through repeated cultivation. Ridomil® MZ 68 WG at a rate of 2.5 kg ha-1 was sprayed on the nursery beds to control damping off. The land was prepared under the standard practice. The experimental plot was cultivated to a depth of 25-30 cm by a tractor, and then the land was leveled and ridges were made manually in each plot. One-month-old seedlings were transplanted to the field. The full rate of blended NPS fertilizer as proposed for each treatment was applied at the time of transplanting, while Nitrogen was applied in splits, half at the time of transplanting and half at 1½ months after transplanting with irrigation water. Similarly, Ridomil® MZ 68 WG at a rate of 2.5 kg ha-1 for controlling fungal disease, Selecron® 720 EC at a rate of 0.75-liter ha-1 for controlling leaf worm, and Mancozeb® (Indofil M-45) at a rate of 2.5 kg ha-1 for controlling early, late blight, and anthracnose was applied. Other horticultural practices were applied according to the National recommendation for the crop (MoA, 2016). The fruits were picked once their skin turned red, with several harvesting cycles carried out for each plot. Harvesting was done from the plants in the three central rows, while the plants in the two outer rows and the two plants at each end of every row were left untouched to prevent border effects.

## 3.5. Data Collection

Crop phenology, growth, yield, and yield components were considered in this study. The details procedures of data collection for all these parameters are presented below.

### 3.5.1. Phonological Data

**Days to 50% flowering:** was recorded as the number of days from transplanting to the time when 50% of plants in each plot flowered.

**Days to 50% maturity** were recorded as the number of days from the date of transplanting to the date when 50% of the plants in each plot reached physiologically maturity of fruits for the first time. In other words, days to maturity were recorded when approximately 50% of plants per plot attained their first crop harvest.

### 3.5.2. Growth, Yield, and Yield-Related Parameters

**Plant height**: The height of the plants was measured from the ground level to the tip of the uppermost part of 5 randomly selected plants at flowering, fruit setting, at first harvest, and final harvest.

**Number of fruits per cluster:** It was recorded by counting the total number of fruits per cluster from five randomly selected plants at the red ripening stage of the fruit, earlier used for flower count.

**Number of marketable and unmarketable fruits per plant:** All fruits produced on plants in the three inner rows of each experimental plot were counted, and damaged fruits due to disease, insect, cracking, and blossom end rot were sorted and counted as unmarketable fruits. The number of marketable and unmarketable fruits per plant was calculated as follows:

Where: MFP = number of marketable fruits per plant

UMFP Where: UMFP = number of unmarketable fruits per plant

**Average fruit weight (grams):** This was calculated from 5 marketable fruits selected from the 2nd, 3rd, and 4th harvest.

**Marketable fruit yield (t ha-1):** was recorded by weighing all harvests of marketable fruits from the three inner rows of each plot and was calculated in tons per hectare.

**Unmarketable fruit yield (t ha-1):** was recorded by weighing all harvests of unmarketable fruits from the three inner rows of each plot and was calculated in tons per hectare.

**Total fruit yield (TFY) (t ha-1):** was recorded as the sum of the weight of marketable and unmarketable fruit yields and was converted to tones per hectare.

### 3.5.3. Partial Budget Analysis

Simple partial budget analysis was employed for economic analysis of fertilizer application, and it was carrying out for combined fruit yield data. The potential response of the crop to the added fertilizer and price of fertilizers during planting ultimately determine the economic feasibility of fertilizer application (Rose *et al*., 2018).

As the rate of application increased, each additional kg of fertilizer had on fruit yield. It would only have paid the farmer to apply fertilizer. To estimate the total costs, the mean current prices of NPS and Urea were collected at the time of planting, and the market price of tomato fruit was taken at harvest. The economic analysis was based on the formula developed by CIMMYT (Zhu, 2014) and given as follows:

**Gross average fruit yield (kg** **ha-1) (AvY)** is the average yield of each treatment.

**Adjusted yield (AjY):** is the average yield adjusted downward by 10% to reflect the difference between the experimental yield and yield of farmers.

AjY = AvY - (AvY-0.1)

**Gross field benefit (GFB):** was computed by multiplying the field/farm gate price that farmers receive for the crop when they sell it as adjusted yield.

GFB = AjY \* field or farm gate price for the crop

**Total cost** is the cost of urea and blended NPS fertilizers used for the experiment. Their prices were based on the 2022 price during planting. The costs of other inputs and production practices, such as labor cost for land preparation, planting, weeding, crop protection, and harvesting was assumed to remain the same or were insignificant among treatments.

**Net benefit (NB):** was calculated by subtracting the total costs from gross field benefits for each treatment.

NB = GFB – total cost

**Marginal return (MR):** is the measure of the increase in return by increasing input and is calculated by dividing the change in net benefit by the change in cost.

MR = ΔNB/ΔTC

**Marginal rate of return (MRR %):** was calculated by multiplying the marginal rate by hundred.

MRR (%) = ΔNB/ΔTC ∗ 1003.7.

### 3.5.4. Data Analysis

Data was subjected to analysis of variance (ANOVA) using SAS version 9.1 Software (SAS, 2001). The treatments mean that were significantly different were separated using the least significant difference (LSD) at a 5% level of significance.

# RESULT AND DISCUSSION

## Days to Flowering and Maturity

Analysis of variance revealed that both days to 50% flowering and days to maturity were significantly affected by variety and NPS fertilizer. However, the interaction between variety and NPS fertilizer had no significant influence on these phenological parameters (Appendix Table 1). The Gelilema variety exhibited earlier flowering and maturity compared to the Cochoro and Chali varieties (Table 1). This finding aligns with Habtie (2022), who also reported that the Gelilema variety had shorter flowering and maturity days than the other tested varieties.

The application of the highest rate of NPS fertilizer (200 kg ha-1) significantly delayed the days to 50% flowering and maturity in tomato varieties. While tomato varieties grown without any fertilizer reached 50% flowering and maturity much earlier. There was no significant difference in days to flowering and maturity when 50 and 100 kg ha-1 NPS fertilizers were applied (Table 1). The delay in flowering and maturity observed with higher NPS fertilizer rates could be attributed to an excess supply of nitrogen, phosphorus, and sulfur, which promotes excessive vegetative growth and potentially delays reproductive growth by reducing the sink strength of flowers compared to vegetative tissues. This phenomenon has been previously reported, indicating that high levels of nitrogen, higher rates of phosphorus, and sulfur application can lead to excessive vegetative growth, thereby delaying the setting and maturity of tomato fruits (Nishat *et al*., 2021; Zhang *et al*., 2024).

Table . Effect of varieties and application of NPS fertilizer rates on days to fruiting and maturity of tomato varieties at Gursum in 2023.

|  |  |  |
| --- | --- | --- |
| Variety | Days 50% to flowering | Days to maturity |
| Cochoro | 54.07a | 85.06a |
| Chali | 50.87b | 83.13b |
| Gelilema | 49.40c | 80.67c |
| LSD (5%) | 0.81 | 1.38 |
| NPS fertilizer rates (kg/ha) |  |  |
| N0 | 48.77d | 78.44d |
| N50 | 49.78cd | 80.89c |
| N100 | 50.77c | 82.67c |
| N150 | 52.44b | 84.89b |
| N200 | 55.44a | 87.89a |
| LSD (5%) | 1.05 | 1.78 |

Mean values followed by the same letter (s) within the column of each treatment are not significantly different from each other at the 5% level of significance. LSD (5%): Least Significant Difference at P<0.05.

## 3.2. Growth Parameters

### 3.2.1. Plant Height

The analysis of variance revealed that plant height was significantly affected by the main effect of NPS fertilizer (p<0.05), but not by variety or the interaction between the two main effects (Appendix Table 1). This indicates that while there was no difference in plant height among the varieties, different levels of NPS fertilizer resulted in varying plant heights in tomatoes. This finding is consistent with Nishat et al. (2021), who reported that different rates of nitrogen and phosphorus application led to varying plant heights in tomatoes.

The tallest plant (66.51 cm) was recorded from the application of higher NPS fertilizer rates (200 kg ha-1) while the shortest plant was measured from the plot not receive NPS fertilizer (Table 2). In addition, the result showed that the plant height increment was related to an increase in the application of NPS fertilizer. This might be related to cell elongation due to increased nitrogen and phosphorus in tomato growth. Research indicates that higher rates of NPS fertilizer, particularly 240 kg/ha, lead to optimal growth performance, enhancing plant height, number of leaves, and branches (Kebede, 2019). Similarly, nitrogen levels also play a crucial role, with studies demonstrating that 150 kg/ha of nitrogen fertilizer resulted in substantial increases in plant height and other growth metrics (Beyene & Mulu, 2019.

**3.2.2. Number of fruits per cluster**

The main effect of variety and application of NPS fertilizer had a significant effect on the number of fruits per cluster. However, the interaction of the two main effects had no significant effect on the number of fruits per cluster (Appendix Table 1). The highest number of fruits per cluster was 5.60 or 5.41 was recorded from varieties Chali and Gelilema, without a statistically significant difference (Table 2). A similar number of fruits per cluster from both varieties was found by Habtie (2022).

The highest number of fruits per cluster was 6.3, was recorded from the application of higher NPS fertilizer rates of 200 kg ha-1 (Table 2). The increased number of fruits per cluster in plots that received higher fertilizer rates might be attributed to the sufficient nutrient supply, which enhances tomato plant growth and fruit development (Bekbayeva *et al*., 2021). Similarly, Nishat *et al*., (2021) reported that the lowest number of fruits per cluster was observed in plots without fertilizer application, while the highest number was recorded in plots receiving the highest nitrogen rates from inorganic fertilizers.

Table . Effect of varieties and application of NPS fertilizer rates on plant height (cm)and number of fruits per cluster Average fruit weight (grams) of tomato at Gursum in 2023.

|  |  |  |
| --- | --- | --- |
| Variety | Plant height (cm) | Number of fruits per cluster |
| Cochoro | 57.38 | 4.10b |
| Chali | 59.12 | 5.41a |
| Gelilema | 59.18 | 5.60a |
| LSD (5%) | NS | 0.54 |
| NPS fertilizer rates (kg ha-1) |  |  |
| N0 | 51.28e | 3.93c |
| N50 | 54.33d | 4.43c |
| N100 | 57.07c | 5.22b |
| N150 | 63.61b | 5.3b |
| N200 | 66.51a | 6.3a |
| LSD (5%) | 2.26 | 0.72 |

Mean values followed by the same letter (s) within the column of each treatment are not significantly different from each other at the 5% level of significance. LSD (5%): Least Significant Difference at P<0.05. NS: nonsignificant

## 3.3. Yield and Yield-Related Parameters

### 3.3.1. Marketable fruit yield

The analysis of variance indicated that the marketable fruit yield was significantly influenced (p<0.05) by the main effects of NPS fertilizer and variety, but not by their interaction (Appendix Table 2). The highest marketable fruit yield (40.03 t ha-1) was observed in the Gelilema variety, while the Chali and Cochoro varieties produced the lowest yields, with no significant difference between them (Table 3). These findings are consistent with Habtie (2022), who also reported that the Gelilema variety had a superior marketable fruit yield compared to Chali and Cochoro.

The highest marketable fruit yield, 42.76 t ha⁻¹, was achieved with the application of 150 kg ha⁻¹ NPS fertilizer, with no significant yield difference compared to the 40.98 t ha⁻¹ yield at the 200 kg ha⁻¹ NPS fertilizer rate. In contrast, the lowest yield, 27.07 t ha⁻¹, was recorded from plants that did not receive NPS fertilizer, which was not significantly different from the yield of plants that received 50 kg ha⁻¹ NPS fertilizer (Table 3). The increased marketable fruit yield can be attributed to the adequate supply of nutrients (N, P, and S) from higher rates of NPS fertilizer, resulting in higher fruit yields. These findings align with previous studies, which have shown that nutrient supply from both organic and inorganic fertilizers enhances plant growth and development, thereby increasing tomato yields (Bekbayeva *et al*., 2021; Nishat *et al*., 2021; Zhang *et al.*, 2024).

### 3.3.2. Unmarketable fruit yield

The analysis of variance showed that unmarketable fruit yield was significantly influenced by the main effect of variety and NPS fertilizer (p<0.05), but not the interaction between the two main effects (Appendix Table 2). This finding aligns with Awoke *et al*. (2021), who reported that the main effect of variety and NPS fertilizer significantly impacted yield components, including unmarketable fruit yield, in hot pepper varieties in Southern Ethiopia, without significant interaction effects between fertilizer rates.

The highest unmarketable fruit yield, 7.30 t ha⁻¹, was achieved with the application of 200 kg ha⁻¹ NPS fertilizer This yield was not significantly different from the yield obtained with 150 kg ha⁻¹ NPS fertilizer. In contrast, the lowest yield, 3.32 t ha⁻¹, was recorded from plants that did not receive NPS fertilizer, which was not significantly different from the yield of plants that received 50 kg ha⁻¹ NPS fertilizer (Table 3). Similar results were also reported by Ger *et al*. (2024), who found that the highest unmarketable fruit yield was obtained with the application of 200 kg ha⁻¹ NPS fertilizer.

Table . Effect of varieties and application of NPS fertilizer rates on marketable fruit yield (t ha-1), and unmarketable fruit yield (t ha-1) of tomato at Gursum in 2023.

|  |  |  |
| --- | --- | --- |
| Variety | Marketable fruit yield (t ha-1) | Unmarketable fruit yield (t ha-1) |
| Cochoro | 31.46c | 4.96b |
| Chali | 34.71b | 5.1674ab |
| Gelilema | 40.03a | 5.9259a |
| LSD (5%) | 3.24 | 0.78 |
| NPS fertilizer rates (kg ha-1) |  |  |
| N0 | 27.04c | 3.32c |
| N50 | 30.10c | 3.86c |
| N100 | 36.13b | 5.13b |
| N150 | 42.76a | 7.12a |
| N200 | 40.98a | 7.30a |
| LSD (5%) | 4.18 | 1.01 |

Mean values followed by the same letter (s) within the column of each treatment are not significantly different from each other at 5% level of significance. LSD (5%): Least Significant Difference at P<0.05.

### 3.3.3. Total fruit yield

The variance analysis revealed that the total fruit yield was significantly affected (p<0.05) by the main effects of NPS fertilizer and variety, but not by their interaction (Appendix Table 2). The Gelilema variety achieved the highest total fruit yield (45.96 t ha-1), whereas the Chali and Cochoro varieties had the lowest yields, with no significant difference between them (Table 3). These results align with Habtie (2022), who also found that the Gelilema variety outperformed Chali and Cochoro in terms of total fruit yield.

The application of 200 kg ha⁻¹ NPS fertilizer resulted in the highest total fruit yield of 49.88 t ha⁻¹, without significant difference from the plot that received 150 kg ha⁻¹ NPS fertilizer. Conversely, the lowest yield of 30.37 t ha⁻¹ was observed in plants that did not receive any NPS fertilizer, which was not significantly different from the yield of plants treated with 50 kg ha⁻¹ NPS fertilizer (Table 4). The increase in total fruit yield can be attributed to the sufficient supply of nutrients (N, P, and S) from higher rates of NPS fertilizer. These results are consistent with previous studies, which have demonstrated that nutrient supply from both organic and inorganic fertilizers enhances plant growth and development, thereby increasing tomato yields (Bekbayeva et al., 2021; Nishat et al., 2021; Zhang et al., 2024).

Table 4. Effect of varieties and application of NPS fertilizer rates on total fruit yield (t ha-1) and average fruit weight (grams) of tomato at Gursum in 2023.

|  |  |  |
| --- | --- | --- |
| Variety | Total fruit yield  (t ha-1) | Average fruit weight (grams) |
| Cochoro | 36.42b | 70.78a |
| Chali | 39.88b | 56.873b |
| Gelilema | 45.96a | 58.66 b |
| LSD (5%) | 3.56 | 4.93 |
| NPS fertilizer rates (kg ha-1) |  |  |
| N0 | 30.37c | 54.17c |
| N50 | 33.96c | 59.08bc |
| N100 | 41.26b | 61.05b |
| N150 | 48.29a | 67.6a |
| N200 | 49.88a | 68.6a |
| LSD (5%) | 4.60 | 6.37 |

Mean values followed by the same letter (s) within the column of each treatment are not significantly different from each other at 5% level of significance. LSD (5%): Least Significant Difference at P<0.05.

### 3.3.4. Average fruit weight

The analysis of variance results showed that average fruit weight was significantly (p<0.05) influenced by both variety and NPS fertilizer. However, the interaction between these two factors did not have a significant effect (Appendix Table 2). The highest average fruit weight (70.78 g) was recorded for the variety Cochoro, followed by Gelilema and Chali, with no significant differences between the latter two (Table 4). Similar results were reported by Masho *et al*. (2016) and Girma *et al*. (2023), who also found the maximum fruit weight in the variety Cochoro.

The application of 200 kg ha⁻¹ NPS fertilizer resulted in the highest average fruit weight of 68.6 g, which was not significantly different from the plot that received 150 kg ha⁻¹ NPS fertilizer. On the other hand, the lowest fruit weight of 54.17 g was recorded in plants that did not receive any NPS fertilizer, which was not significantly different from the fruit weight of plants treated with 50 kg ha⁻¹ NPS fertilizer (Table 4). This result is consistent with Ger et al. (2024), who found the maximum fruit weight in plots treated with higher NPS fertilizer compared to the control plots. Additionally, this result is linked to EIAR (2018), which categorized standard fruit weight into the following size categories: large (>71 g), medium (60–70 g), and small (31–59 g).

## 3.4. Partial Budget Analysis

Tomato variety and application of NPS fertilizer significantly affected marketable fruit yield. Therefore, the economic analysis was performed on the combined results using the partial budget technique as described by CIMMYT (1988). The result of the partial budget analysis has been presented in a tabular form (Table 5 and Appendix Table 3). The Gelilema variety with the application of 150 kg ha⁻¹ NPS fertilizer achieved the highest net benefit of 770,451.5 Birr per hectare and the highest benefit-cost ratio of 7.16. This was closely followed by the same variety with the application of 200 kg ha⁻¹ NPS fertilizer, which resulted in a net benefit of 736,715.5 Birr per hectare and a benefit-cost ratio of 6.74. On the other hand, the Cochoro variety without any fertilizer application had the lowest net benefit of 321,867.5 Birr per hectare and a benefit-cost ratio of 3.14 (Appendix Table 3).

The findings revealed that increasing the rates of NPS fertilizer led to higher net benefits and benefit-cost ratios, with the optimal rate being 150 kg ha⁻¹ NPS fertilizer. The three tomato varieties tested showed the highest net benefits and benefit-cost ratios when different rates of NPS fertilizer were applied. This suggests that producers have multiple options for cultivating tomato varieties by applying varying rates of NPS fertilizer, taking into account the net benefit, benefit-cost ratio, and other fruit characteristics preferred by producers.

The highest marginal rate of return (MRR) of 51.73 (5173.26%) was recorded for plants that received 150 kg ha⁻¹ NPS fertilizer, while the lowest MRR of 26.984 (2698.4%) was observed for plants that received 50 kg ha⁻¹ NPS fertilizer (Table 5). Specifically, the Gelilema variety with the application of 150 kg ha⁻¹ NPS fertilizer had the highest MRR of 55.62 (5562.28%). The highest MRR estimated based on a specific variety and rate of NPS fertilizer had a 3.89 (389.02%) MRR advantage over the highest MRR estimated based on the mean marketable fruit yield of varieties.

Table 5. Net Benefit and Marginal Rate of Return from Partial Budget Analysis for Three Tomato Varieties at Different NPS Fertilizer Rates, Gursum, 2023

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Rate NPS kg ha-1 | MFY t ha-1 | Adj MFY t ha-1 | TVC ETB ha-1 | GFB ETB ha-1 | NB ETB ha-1 | Benefit-cost ratio | Absolute MRR | MRR (%) |
| N0 | 27379.3 | 24641.4 | 102267 | 492828 | 390562 | 3.81 |  |  |
| N50 | 30100 | 27090 | 104017 | 541800 | 437784 | 4.20 | 26.984 | 2698.4 |
| N100 | 36131.3 | 32518.2 | 105767 | 650364 | 544598 | 5.14 | 44.0103 | 4401.03 |
| N150 | 42759.7 | 38483.7 | 107517 | 769674 | 662158 | 6.15 | 51.7326 | 5173.26 |
| N200 | 40982 | 36883.8 | 109267 | 737676 | 628410 | 5.75 | 33.9783 | 3397.83 |

MFY kg ha-1= Marketable fruit yield, AdjMFY kg ha-1= Adjusted fruit marketable yield, TVC ETB ha-1=Total variable cost Birr per hectare, GFB ETB ha-1= Gross farm benefit Birr per hectare; NB ETB ha-1=Net benefit Birr per hectare, and Absolute MRR and MRR (%)= Marginal rate of return as absolute (ratio) and percentage estimates, respectively. Cost and benefit estimated based on 1 kg NPS and Urea fertilizers were 35 and 33 Birr, respectively, at time of planting, One seedling of tomato varieties =0.5 Birr, 82300 Birr for one hectare cultivation and 1 kg of fruit= 20 Birr.

Several studies have recommended treatments not only based on MRR but also considering absolute net return, benefit-cost ratio, and yield (Ger et al., 2024; CIMMYT, 1988). Therefore, producing tomato fruits from the Gelilema variety with the application of 150 kg ha⁻¹ NPS fertilizer at Gursum could be a viable option. This is despite the non-significant mean squares of the variety x NPS fertilizer interaction for marketable fruit yield, as this treatment combination offers the highest marginal rate of return, absolute net benefit, and benefit-cost ratio to producers.

# CONCLUSIONS

In the Gursum District, tomato production is predominantly undertaken by smallholder and commercial farms for market purposes. However, challenges such as soil nutrient deficiencies, limited access to improved varieties, and difficulties in optimal fertilizer application affect yields and profitability. This study aimed to evaluate the response of different tomato varieties to various rates of NPS (Nitrogen, Phosphorus, and Sulfur) fertilizers, identifying the optimal variety and fertilizer rate to maximize fruit yield and economic benefits under local production constraints. The experiment was conducted in the Gursum District of Ethiopia with a randomized complete block design (RCBD), involving three tomato varieties (Cochoro, Chali, and Gelilema) and five NPS fertilizer rates: 0 kg ha⁻¹ (control), 50 kg ha⁻¹, 100 kg ha⁻¹, 150 kg ha⁻¹, and 200 kg ha⁻¹. Analysis of variance showed that both tomato variety and NPS rates significantly affected key parameters such as days to 50% flowering and maturity, number of fruits per cluster, marketable and unmarketable fruit yield, total fruit yield, and average fruit weight. The interaction of variety and NPS rates did not significantly affect these parameters, indicating that they influenced the outcomes independently. Notably, the highest marketable fruit yield (42.76 t ha⁻¹) was achieved with 150 kg ha⁻¹ of NPS fertilizer, slightly outperforming the 200 kg ha⁻¹ rate. This suggests 150 kg ha⁻¹ is the most effective rate for yield maximization. The control group produced the lowest yields, highlighting the critical role of NPS fertilizer in enhancing tomato production. In conclusion, applying 150 kg ha⁻¹ of NPS fertilizer to the Gelilema variety is recommended for optimizing tomato yield and profitability in Gursum. Further experiments across different seasons and locations are needed for robust recommendations.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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# APPENDIX

Appendix Table . Mean squares from analysis of variance for phenology and growth traits of tomato as affected by varieties and application of NPS fertilizer at Gursum in 2023.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Df | Days to flowering | Days to maturity | Plant height | Number of fruits per cluster |
| Replication | 2 | 3.755 | 3.622 | 10.98 | 4.5842 |
| Variety (Var) | 2 | 85.422\*\* | 72.956\*\* | 15.616ns | 10.024\*\* |
| NPS | 4 | 61.566\*\* | 118.756\*\* | 363.745\*\* | 7.382\*\* |
| Var x NPS | 8 | 1.95ns | 3.706ns | 5.255ns | 0.720ns |
| Error | 28 | 1.1841 | 3.432 | 5.523 | 0.5261 |
| Grand Mean |  | 51.444 | 82.956 | 58.564 | 5.0378 |
| CV (%) |  | 2.12 | 2.23 | 4.01 | 14.4 |

\*and \*\*, significant at P< 0.05 and P<0.01, respectively. ns= nonsignificant. Df= degree of freedom. CV (%) =percentage coefficient of variation.

Appendix Table . Mean squares from analysis of variance for fruit yield traits of tomato as affected by varieties and application of NPS fertilizer at Gursum in 2023.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | Df | Marketable fruit yield | Unmarketable fruit yield | Total fruit yield | Average fruit weight |
| Replication | 2 | 31.605 | 0.822 | 42.594 | 3.7556 |
| Variety (Var) | 2 | 281.299\*\* | 3.878\* | 350.177\*\* | 85.422\*\* |
| NPS | 4 | 413.382\*\* | 29.970\*\* | 661.985\*\* | 61.5\*\* |
| Var x NPS | 8 | 7.227ns | 0.7526ns | 9.764ns | 1.95ns |
| Error | 28 | 18.791 | 1.1103 | 22.743 | 1.1841 |
| Grand Mean |  | 35.404 | 5.3511 | 40.755 | 51.444 |
| CV (%) |  | 12.24 | 19.69 | 11.7 | 2.12 |

\*and \*\*, significant at P< 0.05 and P<0.01, respectively. ns= nonsignificant. Df= degree of freedom. CV (%) =percentage coefficient of variation.

Appendix Table . Net benefit and marginal rate of return from partial budget analysis for three tomato varieties at different NPS fertilizer rates, Gursum 2023

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Variety\*NPS | MFY t ha-1 | Adj MFY | TVC ETB ha-1 | GFB ETB ha-1 | NB ETB ha-1 | Benefit-cost ratio | Absolute MRR | MRR (%) |
| VCh N0 | 26314 | 23682.6 | 102266.5 | 473652 | 371385.5 | 3.631546 |  |  |
| VCh N50 | 30676 | 27608.4 | 104016.5 | 552168 | 448151.5 | 4.308465 | 43.8662 | 4386.62 |
| VCh N100 | 35413 | 31871.7 | 105766.5 | 637434 | 531667.5 | 5.026804 | 45.7948 | 4579.48 |
| VCh N150 | 41467 | 37320.3 | 107516.5 | 746406 | 638889.5 | 5.942246 | 50.9531 | 5095.31 |
| VCh N200 | 39689 | 35720.1 | 109266.5 | 714402 | 605135.5 | 5.538161 | 33.3928 | 3339.28 |
| VCo N0 | 23563 | 21206.7 | 102266.5 | 424134 | 321867.5 | 3.147341 |  |  |
| VCo N50 | 26012 | 23410.8 | 104016.5 | 468216 | 364199.5 | 3.501363 | 24.1897 | 2418.97 |
| VCo N100 | 34436 | 30992.4 | 105766.5 | 619848 | 514081.5 | 4.860532 | 54.9182 | 5491.82 |
| VCo N150 | 38036 | 34232.4 | 107516.5 | 684648 | 577131.5 | 5.367841 | 48.6217 | 4862.17 |
| VCo N200 | 36258 | 32632.2 | 109266.5 | 652644 | 543377.5 | 4.972956 | 31.6442 | 3164.42 |
| VG N0 | 32261 | 29034.9 | 102266.5 | 580698 | 478431.5 | 4.678282 |  |  |
| VG N50 | 33612 | 30250.8 | 104016.5 | 605016 | 500999.5 | 4.816539 | 12.896 | 1289.6 |
| VG N100 | 38545 | 34690.5 | 105766.5 | 693810 | 588043.5 | 5.559828 | 31.3177 | 3131.77 |
| VG N150 | 48776 | 43898.4 | 107516.5 | 877968 | 770451.5 | 7.165891 | 55.6228 | 5562.28 |
| VG N200 | 46999 | 42299.1 | 109266.5 | 845982 | 736715.5 | 6.742373 | 36.8977 | 3689.77 |

VCh= Variety Chali; VCo= Variety Cochoro; VG= Variety Gelilema; MFY kg ha-1= Marketable fruit yield, AdjMFY kg ha-1= Adjusted fruit marketable yield, TVC ETB ha-1=Total variable cost Birr per hectare, GFB ETB ha-1= Gross farm benefit Birr per hectare; NB ETB ha-1=Net benefit Birr per hectare, and Absolute MRR and MRR (%)= Marginal rate of return as absolute (ratio) and percentage estimates, respectively. Cost and benefit estimated based on 1 kg NPS and Urea fertilizers were 35 and 33 Birr, respectively, at time of planting, One seedling of tomato varieties =0.5 Birr, 82300 Birr for one hectare cultivation and 1 kg fruit= 20 Birr.