



MEKELLE UNIVERSITY

**Effects of Bentonite Clay-Starch Coated Urea Fertilizer Rates on Tomato (*Solanum lycopersicum*)
Growth and Yield in Mekelle, Tigray, Ethiopia**

By

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A Thesis

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College of Dryland Agriculture and Natural Resources**

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DECLARATION

I, Azeb Berihu, hereby present for consideration by the Department of Plant and Horticultural Sciences within the College of Dryland Agriculture and Natural Resources at Mekelle University, my Thesis entitled Effects of Starch-Bentonite Clay Coated Urea Fertilizer on Growth and Yield of Tomato (*Solanum lycopersicum*) in partial fulfillment of the requirement for the degree of Masters in Horticulture. I sincerely declare that this thesis is the product of my own efforts. No other person has published a similar study which I might have copied, and at no stage will this be published without my consent and that of the Department of Plant and Horticultural Sciences

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BIOGRAPHICAL SKETCH

The author, Azeb Berihu was born on 23/8/1990 E.C in Enticho, Tigray Regional State, Ethiopia from her father Berihu Gebrerufael and her mother Letay Gebrehiwet. She completed her Elementary and Secondary School education from 1997 to 2008 E.C at Golagul Elementary and Brhan Ahform Secondary School, respectively. In 2009, she joined Mekelle University and graduated in July 2011 E.C with the degree of Bachelor of Science in Horticulture Science. Following her graduation, she was employed by Mekelle University and served as a Graduate Assistant. After one year of service, she joined the Post graduate Program at Mekelle University in 2013 E.C to pursue her MSc Degree in Horticulture.

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ABBREVIATIONS AND ACRNOMS

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CIMMYT	International Maiz and Wheat Improvement Center
CRN	Control Release Nitrogen
CV	Co-efficient of Variance
DAP	Di-ammonium Phosphate
FAO	Food and Agriculture Organization
LSD	Least Significant Difference
MARC	Melkasa Agricultural Research Center
MoARD	Ministry of Agriculture and Rural Development
MRR	Marginal Rate of Return
N	Nitrogen
NUE	Nitrogen Use Efficiency
OC	Organic Carbon
OM	Organic Matter
P	Phosphorus
P ₂ O ₅	Phosphotus pentoxide
RCBD	Randomized Complete Block Design
RDF	Recommended Doses of Fertilizer
SRN	Slow Release Nitrogen

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ABSTRACT

N loss from applied urea fertilizer in the soil is a major challenge due to its high volatile behavior, high leaching, low usage efficiency, excessive solubility rate. In this study, a field experiment was conducted in order to investigate the effects of different rates of coated urea fertilizer with bentonite clay-starch on growth and yield of tomato. The experiment was laid out in a Randomized Complete Block Design (RCBD). Treatments consisted four different nitrogen levels (0, 40, 80, 120 kg ha⁻¹) using coated and uncoated urea fertilizers replicated four times. Data on plant height, number of primary branches per plant, number of leaves per plants, fruit diameter, number of fruits cluster per plant, weight of single fruit and fruit yield were collected from five plants which were randomly selected from the middle rows of each plot, and the data were made to statistical analysis significance of treatments and comparison of treatment means. The statistical analysis showed that was a significant ($P < 0.05$) difference among treatments for all parameters. The application of 40 kg ha⁻¹ coated nitrogen fertilizer provided 31.9, 27.9 and 74.1%% increment of plant height, number of leaves and number of primary branches, respectively over the control treatment. Furthermore, application of 40 kg ha⁻¹ coated nitrogen fertilizer increased the number of fruit cluster per plant and yield of tomato fruit per hectare by 124.1 and 60% over the control treatment, respectively. However, tomato yield was at parity between 40N kg ha⁻¹ coated and 120 kg N ha⁻¹ uncoated urea per hectare. Coated urea having 40 kg N ha⁻¹ had the highest NUE (1,645.3). Results indicated that the application of bentonite clay-starch coated urea fertilizers significantly improved plant growth, yield, and nitrogen use efficiency compared to uncoated urea. Economic analysis, showed that coated urea having 40 kg N ha⁻¹ highest profitability. Therefore, farmers should use 40 kg N ha⁻¹ coated urea fertilizers, as these levels have shown significant improvements in tomato yield and profitability.

Key words: *Bentonite clay, coated urea, fertilizer, starch, tomato growth, and tomato yield*

CHAPTER ONE: INTRODUCTION

1.1. Back ground information

Tomatoes (*Solanum lycopersicum L.*) which belongs to the Solanaceae family is originated from South and Central America (Beyene & Mulu, 2019). The crop is highly valued for their edible fruits, which are rich in vitamins, minerals, antioxidants, and other essential nutrients (Beyene & Mulu, 2019; Brasesco *et al.*, 2019; Asfaw, 2021; Nie *et al.*, 2022); Swamy, 2023; Shewangizaw *et al.*, 2024). The consumption of tomatoes has been linked to the prevention of various human diseases, emphasizing their importance in diets worldwide (Mustafa *et al.*, 2022; Nishat *et al.*, 2021; Shewangizaw *et al.*, 2024). Fruits of tomatoes are primarily composed of water (about 95%) and are rich in vitamins and minerals, especially vitamin C, potassium, and lycopene, an antioxidant associated with health benefits like reduced heart disease and cancer risk (Quinet *et al.*, 2019; Swamy, 2023; Shewangizaw *et al.*, 2024).

They have low levels of protein (0.9 g), fat (0.2 g), and carbohydrates (3.9 g), with up to 3% sugar (Swamy, 2023). Tomatoes also contain carotenes, including lycopene and beta-carotene, as well as tomatine, an alkaloid that decreases as the fruit ripens. A 100-gram raw tomato contains about 18 calories, 2.6 g of sugar, and 1.2 g of fiber (Abera *et al.*, 2020; Kabir, 2021; Luo *et al.*, 2023; Swamy, 2023). When it comes to its nutritional value and strong biological activity in the human diet, it ranks top among all vegetables (Abera *et al.*, 2020). Tomato is among the most widely grown vegetables in the world (Frias-moreno *et al.*, 2014; Beyene & Mulu, 2019; Kabir, 2021; Shewangizaw *et al.*, 2024).

Globally, tomato production has seen a remarkable increase, with a 71% rise from 2000 to 2022, reaching 186 million tonnes in 2022, making tomatoes the most produced vegetable. This growth

is driven by rising consumer demand and improved agricultural practices (Brief, 2022). China leads in production, while Egypt is the top producer in Africa (Girma *et al.*, 2023). In Ethiopia, tomatoes are the primary commercial vegetable, yielding 164 million tonnes annually from 4.73 million hectare (Beyene & Mulu, 2019). The country's diverse climate and soil conditions favor the cultivation of various fruits and vegetables, with tomatoes thriving at altitudes of 700 to 2200 meters sea level and widely cultivated in tropical, subtropical and temperate climates, with the exception of colder regions (Girma *et al.*, 2023; Beyene & Mulu, 2019; Lendabo *et al.*, 2021; Shewangizaw *et al.*, 2024).

However, Ethiopia's average tomato yield is low, ranging from 6.5 to 24 metric tons per hectare, which is significantly below the global averages of 34 metric tons per hectare (Beyene & Mulu, 2019; Getachew & Gemechu, 2019; Girma *et al.*, 2023). The total area of land estimated to be covered by tomato is estimated to be 7,255 ha with an average yield of 6.5 to 24.0 MT/ha out of this Tigray region contributes for about 5% the national average tomato production (Beyene & Mulu, 2019; Asfaw, 2021; Ashebre, 2021). Productivity of tomato is very low due to several factors. Among these, low soil fertility, erratic rainfall, and inadequate fertilizer application hinder optimal yields (Sigaye *et al.*, 2022).

A major concern is the significant nitrogen (N) losses from urea fertilizer application, ranging from 30% to 60% in tropical soils, primarily due to rapid hydrolysis by urease enzymes that increase pH and ammonium levels, negatively affecting seedling growth (Khan *et al.*, 2015). Urea, containing 46% nitrogen, is widely used for high crop yields but is prone to volatilization, leading to economic losses, reduced nutrient efficiency, and negative environmental impacts (Sigaye *et al.*, 2022; Nie *et al.*, 2022; Wei *et al.*, 2024; Mustafa *et al.*, 2022; Bakar *et al.*, 2024;

Olowoake et al., 2024; Swify *et al.*, 2024; Coggins et al., 2025). Effective nitrogen management can enhance yield and quality, making it critical for optimizing agricultural practices, especially with nitrogenous fertilizers like urea (Beyene & Mulu, 2019). Nitrogen (N) is a vital macronutrient for tomato growth, essential for photosynthesis and protein synthesis (Yaseen, 2021; Balaganesh *et al.*, 2021; Lagos, 2022; Mustafa *et al.*, 2022; Ahmad et al., 2022; Liu *et al.*, 2022). Nitrogen fertilizers are also essential for the growth and development of tomato plants, resulting in increased fruit production (Kabir, 2021; Olowoake *et al.*, 2024; Shewangizaw et al., 2024).

These fertilizers utilize various methods and materials to manage nitrogen release, and to minimize excess in the soil. This helps prevent ammonium loss as ammonia into the air and reduces nitrate leaching into water sources, thereby decreasing water and air pollution (Swify *et al.*, 2024). Early-stage N losses were also greatly decreased by the fertilizer's prolonged slow-release impact, which led to a 7.5–30.4% decrease in overall fertilizer N losses (Wei *et al.*, 2024). To address these issues, research is exploring the effectiveness of slow-release fertilizers, such as bentonite clay and starch-coated urea, to improve nitrogen use efficiency and reduce losses. These environmentally friendly options are cost-effective, biodegradable, and can help retain nitrogen and micronutrients at the application site (Hassan, 2018); Aleckiené, 2022; Neto et al., 2023; In *et al.*, 2024). Overall, optimizing nitrogen management and exploring innovative fertilizer solutions are essential for improving tomato production and ensuring food security for the growing population.

1.2. Statement of the Problem and Justification

Increasing crop yield using fertilizer as primary input is becoming an important factor in meeting everyone's food security (Ahmad & Yaseen, 2021; Cui *et al.*, 2022; Neto *et al.*, 2023; Bakar *et al.*, 2024; Swify *et al.*, 2024). On the contrary, the huge loss of N from urea fertilizer applied in the soil is a major challenge worldwide due to the high volatile behavior, high leaching, low usage efficiency, excessive solubility rate. Only 30-40% of the entire dosage of urea (the major source of nitrogen) is used by the plant. This means that 60-70% of the applied urea fertilizer is not consumed due to its rapid release and leaching (Mustafa *et al.*, 2022; Sigaye *et al.*, 2022; Neto *et al.*, 2023; Swify *et al.*, 2024; Wei *et al.*, 2024; Bakar *et al.*, 2024). Coated urea and slow-release urea fertilizers present promising alternatives over traditional fertilization methods (Hassan, 2018; Rehman *et al.*, 2021; Swify *et al.*, 2024). Traditional methods may not fully address factors such as water retention, nutrient availability, and leads to nutrient loss, uneven distribution, and environmental concerns (Rehman *et al.*, 2021; Mustafa *et al.*, 2022). Moreover, traditional application methods affect plant development and food safety in addition to polluting the environment and decreasing fertilizer efficacy and toxicity levels (Zhao *et al.*, 2018). Utilization of coated slow-release urea fertilizer is the best solution to address the aforementioned problems. Coated urea fertilizers with bentonite clay and starch-coated urea can improve crop performance by slowly releasing N and its use efficiency by the crop (Hassan, 2018). The application of coated urea fertilizers in tomato plants has not been practiced in the vegetable growing areas in Tigray. Field experiments to investigate the effect of coating urea is highly important to improve crop productivity and N use efficiency (Dong *et al.*, 2016; Neto *et al.*, 2023).

1.3. Objective of the study

1.3.1. General objective

- The General objective of the experiment was to investigate the effects of bentonite clay-starch coated urea fertilizer rates on growth and yield of tomato growth.

1.3.2. Specific objectives

- To assess the influence of bentonite clay and starch coated urea fertilizer on growth and yield parameter of tomato
- To evaluate nitrogen utilization efficiency in tomato due to the impact of coating of urea fertilizer
- To determine the economic feasibility of coated urea fertilizer using bentonite clay-starch on tomato production.

1.4. Hypothesis

The study hypothesized that the application of coated urea fertilizer significantly affects tomato growth, yield, and yield components.

1.5. Significance of the study

The significance of this study lies in its potential contributions to agricultural practices and food security through the exploration of innovative fertilization methods. As the global population continues to grow, increasing crop yields becomes of paramount importance to meet the rising demand for food. Traditional urea fertilizers, while commonly used, present significant challenges including high volatility, leaching, and low nutrient use efficiency, often resulting in only 30-40% uptake by plants. This inefficiency not only undermines crop productivity but also contributes to environmental pollution through nutrient runoff. By investigating the effects of bentonite clay and starch-coated urea fertilizers on the growth and yield of tomatoes, this study

aims to address critical issues related to nutrient retention and availability. The use of coated slow-release fertilizers represents a promising alternative that could enhance nutrient delivery to plants while minimizing environmental impacts. If successful, this approach could lead to improved crop performance, reduced fertilizer costs, and enhanced sustainability in agricultural practices. Moreover, the study contributes to the existing body of knowledge by providing empirical data on the effectiveness of alternative fertilization methods. This research not only aligns with current agricultural trends towards sustainable practices but also addresses the urgent need to optimize fertilizer use in order to secure food production in an eco-friendly manner. Ultimately, the findings could serve as a foundation for future studies and practical applications, promoting better agricultural policies and practices that prioritize both productivity and environmental stewardship.

CHAPTER TWO: LITERATURE REVIEW

2.1 Origin and Distribution

The cultivated tomato (*Solanum lycopersicum*) originated in Mexico, whereas its wild relatives are most diverse in Peru. *Solanum lycopersicum cerasiforme*, its ancestor, is indigenous to Central America (Gutierrez, 2018; Koch *et al.*, 2018; Swamy, 2023). Cultivated tomatoes are connected to wild varieties from Peru, Ecuador, and the Galapagos Islands, and domestication took place primarily in Mexico. These landraces and wild cousins provide important genetic variety for conservation and crop enhancement (Ghafoor & Habib-ur-rahman, 2021; Gutierrez, 2018; Swamy, 2023).

The domesticated tomato and its twelve closest wild relatives are members of the Lycopersicon clade, which is a subfamily of the Solanaceae family, which includes over 3,000 species. *Solanum pimpinellifolium*, a native of western South America that produces pea-sized fruits, is the wild parent of the cultivated tomato (Gutierrez, 2018; Swamy, 2023). The Aztecs and other Mesoamerican societies were the first to domesticate. Because they belong to the nightshade family, which includes deadly species, tomatoes were first cultivated as ornamental plants in Europe when they were brought there by the Spanish. The acidic juice's reactivity with metal plates and the presence of tomatine, a poisonous substance found in unripe fruit and leaves but much lower in mature tomatoes, added to these worries (Gutierrez, 2018; Swamy, 2023).

2.2. Botanical description and classification

2.2.1 Family

The genus *Solanum*, species *Solanum lycopersicum*, tribe Solaneae, and sub-family Soloanoideae are all members of the Solanaceae family, which includes tomatoes (Kimura & Sinha, 2014); Gutierrez, 2018; Kabir, 2021; Swamy, 2023). This family, known as nightshades,

includes other plants like peppers, potatoes, and eggplants, with over 3,000 species in total. Notably, there are more than 7,000 varieties of tomatoes alone (Gutierrez, 2018).

The *Solanum lycopersicum*/*S. esculentum* complex includes seven species that can hybridize with cultivated tomatoes, increasing genetic diversity for variety improvement (Kimura & Sinha, 2014). While botanically classified as fruits (berries), tomatoes are often labeled as vegetables in stores due to their savory taste, similar to bell peppers and cucumbers. The term "pomodoro," meaning "golden apple" in Italian, suggests early European tomatoes were yellow, and the French "pomme d'amour" or "love apple" may reflect its supposed aphrodisiac properties. Some believe tomatoes were initially mistaken for eggplants, referred to as "pomme des Mours". Tomatoes are native to Central, South, and southern North America, particularly the Andean region (Peru, Bolivia, Chile, and Ecuador). The Aztecs and Incas cultivated tomatoes as early as 700 BCE, although these early varieties were smaller and different in taste from modern tomatoes (Swamy, 2023). The wild tomato, characterized by its small size and acidity, was traded among prehispanic cultures and resembled the green tomato (*Physalis*), aiding its adoption.

Tomato plants are flowering angiosperms that reproduce sexually, requiring both male and female organs for seed production. Each seed contains a tiny plant that germinates, beginning with the radicle (root) growing downward and cotyledons (seed leaves) growing upward. as the plant matures, it produces more leaves and flower buds (Gutierrez, 2018; Swamy, 2023). Tomato plants are typically branched, spreading 60–180 cm, with some compact varieties. Their hairy, aromatic leaves can reach up to 45 cm long, and the yellow flowers are about 2 cm across and clustered. The fruits are berries, ranging from 1.5 to over 7.5 cm in diameter, commonly red, scarlet, or yellow, but also green or purple, with various shapes. Each fruit contains small seeds

in jelly like pulp. Tomato seeds mature 35-50 days after pollination, becoming germinable and developing desiccation tolerance as their water content decreases. The cultivated tomato (*Solanum lycopersicum*) usually ripens and turns red about 60 days after pollination (Gutierrez, 2018).

2.2.2 Botanical description

Tomato is a perennial herbaceous plant often grown as an annual, with growth habits that can be indeterminate or determinate, reaching up to 3 meters in height (Rawat et al., 2024). Its primary root can grow several meters long, and the angular stem is covered in hairy, glandular trichomes. Leaves are alternately arranged, varying from lobed to compound, typically with five to nine petiolated, dentated leaflets. The fruit is globular or ovoid, classified as a berry, with a thin outer skin and fleshy wall that contains 50 to 200 small, lentil-shaped seeds enclosed in gelatinous membranes (Gutierrez, 2018).

Tomato seeds consist of an embryo and endosperm, protected by a seed coat called the testa (Swamy, 2023). Fruit development occurs seven to nine weeks post-fertilization (Gutierrez, 2018). Tomato plants are typically branched, growing 60–180 cm, and can be trailing or compact, with hairy, odorous, innately compound leaves up to 45 cm long. The yellow, five-petaled flowers are about 2 cm across and grow in clusters. The fruits, classified as berries, range from 1.5 to 7.5 cm in diameter and can be red, yellow, green, or purple, containing small seeds in jelly like pulp. Tomato plants can grow over 180 cm if supported, while bush varieties are shorter. Indeterminate types are tender perennials that die annually in temperate climates, while determinate types are annual (Kiran et al., 2020).

They are dicots with branching stems and terminal buds that stop growing due to pruning or flowering, allowing lateral buds to develop. The vines can root at ground contact points. Most tomatoes have compound leaves, but some have simple leaves, typically 10–25 cm long with five to nine leaflets. The yellow flowers can self-fertilize and are borne in clusters (Koch et al., 2018). Botanically, tomatoes are berries that develop from the ovary after fertilization, even though they are commonly treated as vegetables in cooking (Gutierrez, 2018). Tomato fruits, known scientifically as *Solanum lycopersicum*, have locular cavities filled with seeds and moisture, with variations based on type: smaller varieties have two cavities, globe-shaped have three to five, beefsteak tomatoes have many small cavities, and paste tomatoes have few (Swamy, 2023).

Tomato plants are dicots with deep root systems (up to 2 meters) and develop into vines with branching stems and a terminal bud. When the terminal bud stops growing, lateral buds form new vines. The leaves can be compound or simple (5-7 leaflets), and both vines and leaves are hairy, which aids in rooting. The yellow flowers, measuring 1-2 cm in diameter, grow on the apical meristem and have five lobes. The fruits are berries containing small, flat seeds. Tomato plants can grow over six feet tall if supported, while bush varieties are about three feet. They are tender perennials that die annually in temperate climates, with various leaf types including regular, potato leaf, rugose, angora, and variegated (Group & Oversight, 2017; Gutierrez, 2018; Swamy, 2023).

2.2.3 Botanical classification

Linnaeus classified the tomato as *Solanum lycopersicum* in 1753, but Philip Miller reclassified it as *Lycopersicon esculentum* in 1768, a name that became popular despite naming rule violations. The name *Lycopersicum* was proposed in 1888 but is not used due to tautonym restrictions

(Gutierrez, 2018). While validated in 1974, *Lycopersicon esculentum* was conserved in 1983 for its familiarity. Genetic evidence supports Linnaeus's classification, making *Solanum lycopersicum* the correct name. Both names are likely to remain in use, with distinctions based on leaf structure and biochemistry, despite evidence of hybridization with potatoes. The genus *Lycopersicon* comprises the cultivated tomato, *L. esculentum*, and seven related wild species (Swamy, 2023). Previous classifications by Muller and Luckwill are now outdated due to new species discoveries in South America. Muller's initial categorization based on fruit color is considered arbitrary. *Lycopersicon* is part of the Solanaceae family, which has about 90 genera, and falls under the Solanoideae sub-family and Tribe Solaneae. *Lycopersicon* is distinguished from *Solanum* primarily by its anther morphology, featuring five anthers that form a flask-shaped cone (Gutierrez, 2018).

The commercial tomato is typically referred to as *Lycopersicon esculentum*, although there is debate over its correct Latin name, with alternatives like *Solanum lycopersicum*. The name *Lycopersicon esculentum* was proposed by Miller in 1768, replacing Linnaeus's classification. Despite classification challenges, *Lycopersicon esculentum* is favored due to its historical usage, reflecting the evolving nature of taxonomic understanding (Group & Oversight, 2017; Gutierrez, 2018).

2.3. Production of Tomato

With 64.768 million mT, or 34.67% of the global production, China is the world's largest tomato producer. China produced tomatoes on 1,107,485 hectares in 2020, with a yield of 58.5 mT/ha per square meter. India, which produced 20.573 million mT of tomatoes on 812,000 hectares in 2020 with an average yield of 25.3 mT/ha, came in second to China. With a yield of 72.6 mT/ha

and 13.204 million mT cultivated on 181,879 hectares, Turkey came in third place. With 110,439 hectares, 12.227 million mT, and a yield of 110.7 mT/ha, the US came in fourth place (Girma et al., 2023). Because of their short harvesting season, relatively high production per hectare (for instance, 9.4 tons per hectare in 2016), and status as one of the strategic commodities the Ethiopian government prioritizes for the development of the agro-industry, tomatoes are crucial to the country's efforts to combat poverty and food in security (Asfaw, 2021).

Additionally, it boosts the country's economy by providing raw materials for value-added agro-processing companies and foreign exchange for tomatoes that can be exported to other countries (for instance, \$9.006 million in revenue from the export of fresh and chilled tomatoes in 2017). The tomato is therefore the most important vegetable in Ethiopia due to these and other factors. Even though tomatoes are important for nutrition, the economy, and human health, their production and productivity were generally low in Ethiopia. For example, in 2016, the total cultivated area was about 9700 hectares, with 91300 tons of fresh tomatoes produced overall and an average productivity of 9.4 tons per hectare (Asfaw, 2021).

2.4. Nutritional Importance of the Tomato

Tomatoes are classified as both a fruit and a vegetable (Gutierrez, 2018). botanically, they are a fruit (a berry), but culinarily, they are treated as vegetables due to their lower sugar content and savory flavor, making them ideal for salads and main courses (Fish, 2020 ; Rawat *et al.*, 2024). This ambiguity also applies to other foods like bell peppers and cucumbers (Ouattara & Konate, 2024). Rich in flavor, tomatoes can be eaten raw or cooked in various dishes. Historically, the Aztecs cultivated many tomato varieties, with red tomatoes called xictomatl and green ones tomatl (tomatillo), and documented their diverse uses in sauces and dishes (Gutierrez, 2018).

Tomatoes are a major global food source, ranking as the largest vegetable in production and consumption (Rawat et al., 2024). Tomatoes are a nutritious food source rich in several important nutrients. A medium tomato provides approximately 17.6 mg of vitamin C (20% of the daily intake), 237 mg of potassium (5% of the daily intake), and is an excellent source of lycopene, a powerful antioxidant linked to lower risks of heart disease and certain cancers. Additionally, it contains about 0.6 mg of vitamin E (3% of the daily intake) and contributes to vitamin K intake, which is essential for blood clotting and bone health (Beyene & Mulu, 2019; Gutierrez, 2018; Swamy, 2023).

2.5. Effect of Nitrogen and Phosphors on the Growth and Yield of Tomato

2.5.1. Nitrogen

Plants require N in the largest amount among the major/primary nutrients (Zewide, 2021). many functions including promotion of rapid growth, increasing leaf sizes and quality, enhancing fruit and seed development; forms an integral component of many important components in plants including amino acids that are building blocks of proteins and enzymes that are involved in catalyzing most biochemical processes (Zewide, 2021); (Sainju et al., 2003). Thus, it plays a role in almost all metabolic processes. As determined by its functions N influences the rate of crop growth and crop quality. while N deficiency in tomato can result from N removal by plant from the soil after the harvest of above ground plant bio mass, absence of soil amendments such as manures and fertilizers. As N applied from manures and fertilizers to the soil is readily converted into NO_3^- for plant uptake, high rate of N fertilization can result in large amount of residual NO_3^- build up in the soil after crop harvested. Because NO_3^- is soluble in water, high concentration of residual NO_3^- can increase the potential for N leaching from the soil and contaminate groundwater. the type of N fertilizer applied can also influence tomato production because $\text{NH}_4\text{-N}$ can be

toxic to tomato growth compared with $\text{NO}_3\text{-N}$ (Zewide, 2021); (Sainju *et al.*, 2003). To obtain a best management practice that can sustain tomato yield, reduce the amount of N fertilization and N leaching, and improve soil quality and productivity. High N level in the soil, on the other hand, can promote excessive vegetative growth and which can delay the setting and maturity of tomato fruits, there by reducing tomato production. The most important component and main input for maintaining crop health and promoting appropriate growth, development, and production is nitrogen (Nishat *et al.*, 2021). It is frequently needed in greater amounts than all other mineral elements put together, underscoring its crucial function in a number of plant physiological processes (Leghari *et al.*, 2016). 32 million tons of nitrogen were consumed worldwide in agriculture in 1970; this amount rose to 100 million tons in 2010 and then to 195 million tons in 2021.

A vital component of protein, which is made up of amino acids and aids in the catalization of chemical reactions and the movement of electrons, and chlorophyll, which facilitates photosynthesis, nitrogen is a primary food source for plants and is found in many important parts of the plant body (Leghari *et al.*, 2016). Numerous physiological functions depend heavily on nitrogen. It gives plants a dark green hue and encourages the growth and development of their leaves, stems, and other vegetative parts. Additionally, it promotes the growth of roots. Nitrogen promotes the uptake and utilization of other nutrients, such as potassium and phosphorus, and regulates the general growth of plants. It also produces quick early growth, improves fruit quality, increases the growth of leafy vegetables, and boosts the protein content of fodder crops reduced growth, chlorosis (the green leaves turning yellow), red and purple patches on the foliage, and restricted lateral bud growth (from which leaves, stem, and branches arise) are all symptoms of a nitrogen deficiency (Fish, 2020). The symptoms of a deficiency typically start on

older leaves, after which leaf senescence begins (Fish, 2020 ; Encapsulation, 2023). Excessive nitrogen application also has negative effects on plant growth, causing the leaves to become more dark-green, making the entire growth succulent, and favoring less fruit with lower quality. Excessive vegetative growth results from overuse of nitrogen, especially in tropical regions (Nishat et al., 2021; Fish, 2020). Only beneficial forms of nitrogen are absorbed by plants; most plants take up nitrogen in the form of nitrate, but in some soils, such as submerged soil, it is ineffective, whereas NH_4^+ is the most appropriate. An ideal amount of nitrogen is necessary for plants to grow and develop properly. Crop production is consistently focused on this topic since too little nitrogen treatment directly lowers crop yield while too much nitrogen also has detrimental effects on plants (Leghari et al., 2016).

2.5.2. Phosphorus

Phosphorus is the second most frequently limiting nutrient for plants. It is a crucial part of ribonucleic acid (RNA), which controls protein synthesis in both plants and animals, and deoxyribonucleic acid (DNA), which is the site of genetic inheritance. Another class of globally significant phosphorus-containing chemicals is phospholipids, which are essential components of biological membranes. Phosphorus is therefore necessary for all plants to be healthy and vigorous in general. Phosphorus has been linked to several distinct growth variables, including: Enhanced root development, stronger stalks and stems, better flower formation and seed production, Increased legumes' ability to fix nitrogen, more consistent and earlier crop maturity, enhanced resilience against plant diseases, better crop quality, and supports the growth of plants throughout their whole life cycle (Sigaye et al., 2022).

Phosphorus is absorbed as the H_2PO_4^- -or HPO_4^{2-} -ion. This complex does not leach readily from the soil and is mobile once in the plant. Phosphorus is rapidly fixed with iron, magnesium, and

aluminum on soil particle, when applied under acidic soil conditions. Phosphorus is a very important macronutrient involved in most growth processes. It is an essential component of most organic compounds in the plant including nucleic acids, proteins, phospholipids, sugar phosphates, enzymes and energy-rich phosphate compound, a common example being adenosine triphosphate (Awad-Allah *et al.*, 2023). Phosphorus helps to initiate root growth of tomato and therefore aids in early establishment of the plant immediately after transplanting or seeding. Starter solution containing high concentration of P is normally applied to tomato plants within a few days after transplanting for early root development and establishment in the soil (Sainju *et al.*, 2003). Phosphorus is especially important for young plants and seedling growth. Phosphorus deficiency in plants is generally expressed in reduced growth, intense coloring, browning or purpling of foliage in some plants, thin stem, reduced lateral breaks, and loss of lower leaves and reduced flowering. Chemical fertilizers, particularly nitrogen (N) and phosphorus (P), are vital for enhancing soil fertility in small-scale agriculture (Sigaye *et al.*, 2022). Insufficient NP fertilizer can cause stunted growth, small leaves, and low fruit yield in tomato plants. Nitrogen promotes vegetative growth and fruit yield, especially in nitrogen-deficient soils like sandy soils. The fuel that propels plant development is nitrogen (Sigaye *et al.*, 2022). It is absorbed from the soil as either ammonium (NH_4^+) or nitrate (NO_3^-). It joins with substances made by the plant's metabolism of carbohydrates to create proteins and amino acids. It is a crucial component of proteins and has a role in all of the main processes that affect plant growth and yield. The plant's ability to absorb other nutrients depends on having a healthy supply of nitrogen, while phosphorus is essential for overall growth, with its deficiency leading to reduced growth and yields (Sigaye *et al.*, 2022).

Tomatoes have the highest phosphorus requirements during early development, and the application rates of nitrogen and phosphorus (NP) fertilizers significantly influence fruit yield and weight (Nishat et al., 2021; Etyisa et al., 2013).

Urea is a popular nitrogenous fertilizer known for its high nitrogen content (46%) and affordability. However, its effectiveness is diminished compared to other nitrogen fertilizers due to its quick release in the soil, which can lead to nitrogen loss. This results in urea moving away from the plant's root zone and becoming unavailable through various processes. As a result, crops typically recover only 30% to 40% of the nitrogen from urea, causing inefficiencies and environmental issues (Hassan, 2018; Rehman et al., 2021; Mustafa et al., 2022; Sigaye et al., 2022).

Nutrient available in the soil is rarely present in balanced conditions to meet the nutrient requirement of important crops. Most soils are only able to supply a fraction of the nutrients added to the soil and this did not give the potential yield of cultivated crops. Continuous cropping with low or no fertilizer inputs, nutrient losses through harvest, soil erosion and leaching has led to decline in soil fertility (Fish, 2020).

2.6. Conventional Urea Application

Conventional urea is inefficient, causing substantial nitrogen loss from the soil (Nie et al., 2022). Urea fertilizer is produced by combining gaseous CO₂ and liquid ammonia under high pressure and temperature, then adding ammonium carbamate and processing it into prills or pellets. It is the primary solid nitrogen fertilizer, especially in developing regions, with 80-85% of production used for this purpose, supporting over 40% of global food production and accounting for 57% of agricultural nitrogen use. demand is expected to grow by 1.5% annually (Swify et al., 2024).

Urea is favored for its high nitrogen concentration (46%) and water solubility, allowing flexible application methods. However, it has nitrogen use efficiency (NUE) of only 50% and faces challenges from nitrogen loss through volatilization, fixation, denitrification, and leaching.

Nitrogen use efficiency (NUE) measures a plant's ability to absorb nitrogen and transform the available nitrogen into economically valuable biomass (Ghafoor & Habib-ur-rahman, 2021; Congreves et al., 2021); Coggins et al., 2025). Farmers frequently use excessive nitrogen to boost crop productivity, leading to environmental issues like soil acidification, groundwater pollution, and increased greenhouse gas emissions (Hassan, 2018; Ahmad & Yaseen, 2021; Ghafoor & Habib-ur-rahman, 2021; Mustafa *et al.*, 2022; Sigaye *et al.*, 2022; Bakar *et al.*, 2024). To mitigate these problems, efficient nitrogen management practices, such as nutrient-coated urea, are urgently needed to enhance nitrogen use efficiency (NUE), crop quality, and yields (Mustafa *et al.*, 2022). By slowing down (preventing) water-soluble nutrients from coming into direct contact with soil and crop roots, N leaching, volatilization, and fixation are reduced (Wei *et al.*, 2024). Controlled-or slow -release nitrogen fertilizers are widely used to reduce nitrogen losses (Ghafoor & Habib-ur-rahman, 2021; Ahmad & Yaseen, 2021; Liu et al., 2022; Sigaye *et al.*, 2022; Mustafa *et al.*, 2022; Genes *et al.*, 2023; Olowoake *et al.*, 2024; Swify et al., 2024; Bakar *et al.*, 2024).

These fertilizers various methods and materials are used to manage nitrogen release, and to minimize excess in the soil. This helps prevent ammonium loss as ammonia into the air and reduces nitrate leaching into water sources, thereby decreasing water and air pollution (Swify et al., 2024). Early-stage N losses were also greatly decreased by the fertilizer's prolonged slow-release impact, which led to a 7.5–30.4% decrease in overall fertilizer N losses (Wei et al., 2024).

Urea must also be hydrolyzed in the soil to be converted it to ammonium for plant use, complicating its effectiveness as a primary nitrogen source (Swify et al., 2024). This is primarily attributed to urea's higher susceptible to nitrogen loss through ammonia volatilization (2–20%), reactions with soil organic matter (15–25%), and leaching (2–10%). Its hydrolysis increases soil pH, causing an average nitrogen loss of 16%, which can exceed 40% in warm, humid conditions. While urea and its fluids are particularly prone to volatilization, all surface-applied ammonia and ammonium fertilizers can also lose nitrogen. Overall, volatilization can lead to a 20–50% nitrogen loss, raising significant environmental concerns (Swify *et al.*, 2024). The simplest and most cost-effective way to improve food production and address the current food security issue is to employ nutrient-coated fertilizers (urea). However, it necessitates careful consideration of the environmental effects, application method, and nutrient source. In most cases, nutrient-coated urea is cost-effective because it only needs to be given once throughout each crop season (Mustafa et al., 2022). Bentonite is natural clay that has been proposed as an effective tool for prevention of nitrogen leaching due to its high safety, good adsorption capacity, abundance, and cost-effectiveness (In *et al.*, 2024; Hassan, 2018).

Bentonite is a kind of clay. It is safe and natural, and it can be applied to soil to make it better. Its capacity to store water and nutrients is exceptional. During dry, it can assist plants in absorbing more water and nutrients. Given to sandy soils, other types of clay additions have been shown to increase the efficiency of water use, reduce evaporation loss, and improve water retention (Hassan, 2018; Al-taey *et al.*, 2023).

Common polysaccharide starch improves dispersion and regulated release by acting as an extender and binder. Because it is abundant, biodegradable, and environmentally benign, starch a

naturally occurring, renewable biopolymer has great potential for use in agriculture (Encapsulation, 2023).

2. 7. Previous Studies on Slow Releases

The use of slow- or controlled-release nitrogen fertilizers enhances nitrogen use efficiency (NUE) and reduces nitrogen loss by minimizing nitrate leaching, volatilization, and nitrous oxide emissions, resulting in a lower environmental impact compared to conventional fertilizers (Swify *et al.*, 2024). These fertilizers also boost crop yields by providing a consistent nitrogen supply, which can increase farmers' profits. Additionally, they promote healthy root growth by allowing roots to penetrate deeper into the soil for nutrients, improving plant resilience to environmental stressors like drought. gradual nutrient release also helps mitigate toxicity levels during the early growth stages, contributing to agronomic safety (Swify *et al.*, 2024).

Controlled- or slow-release fertilizers can positively impact nitrogen use efficiency based on several factors including crop type and soil conditions. The increase in crop yield is the main motivation for producers to use controlled or slow-release fertilizers (Mustafa *et al.*, 2022).

Controlled- or slow-release nitrogen (CRN/SRN) fertilizers effectively boost grain crop yields and can reduce application rates by 20–30% or more compared to conventional fertilizers. They enhance nutrient use efficiency (NUE) by minimizing nitrogen losses through improved plant nutrient uptake, thereby decreasing the nitrogen left in the soil that is prone to environmental loss (Swify *et al.*, 2024).

The use of slow-release fertilizers in strawberry production demonstrated potential advantages in nutrient management. While the study focused on fruit production, the findings underscored the

importance of considering slow-release nitrogen sources for various crops to improve overall yield and quality parameters (Albregts *et al.*, 1991).

The environmental benefits of slow-release nitrogen fertilizers in vegetable production systems. The study highlighted the need to extend nitrogen availability over the growing season to enhance crop nutrient uptake efficiency and minimize environmental risks associated with nitrogen leaching (Sanchez and Doerge., 1999). Studies have demonstrated that crops such as tomatoes, lettuce, and carrots benefit from SRNF, showing higher productivity compared to those grown with conventional fertilizers (Mousavi *et al.*, 2019).

Different studies have been taken on the development of slow-release fertilizer (SRFs) by different researchers at different times (Ye et al. 2019). developed slow-release fertilizer based on biochar using bio-oil coating material and analyzed the release ability before and after the coating. The result revealed that the oil coating treatment dissolve rate of nutrients decreased by about 15% and its leakage property in soil decreased by 3-5%. This proved that the bio-oil film-forming property and its coating treatment strengthen the slow release capacity of fertilizer (Xiao *et al.* 2019). Studied the volatilization of ammonia, leaching of nitrogen, and greenhouse gas emission of bag controlled release fertilizer based on the peach orchard. They have also seen the effect of bag controlled release fertilizer on soil nutrient status, nitrogen utilization and absorption rate, and fruit quality. Their result showed nitrogen leaching is decreased, the volatilization of ammonia is significantly reduced, soil obtained nutrients at a stable rate, fine root development, and improved fruit quality is obtained.

Urea fertilizer coated by grafted cassava starch to obtain sustainable fertilizer release and water-retaining property. N release and water absorbency property comparison made between coated and uncoated urea fertilizer (Jyothi et al., 2018).

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was carried out at Elshadai Relief and Developmental Association's farm with in Mekelle town. More precisely, the experiment was located at 13°27' 283" N and 39°27.996' E with an average altitude of 2161 meters above sea level (Figure 1). The research field's soil has a slightly amount of organic matter and is slightly acidic. The climate of the study area is semi-arid with a mean annual rainfall of 400 mm most of which falls in the main/ heavy rainy season (locally known as Kiremt) and lasts from June to mid-September and light showers that occur from February to May. The monthly mean air temperature throughout the year ranges from 9.41°C in December to 27.37°C in May (Haftu et al., 2023). The textural soil of the experimental site was Sand clay loam with PH of 6.42. The farming system in the study site includes both crop and livestock production. The major cultivated cereal crops are wheat (*Triticum aestivum*), tef (*Eragrostis tef*), hanfets (*Hordeum vulgare* + *Triticum aestivum*), and barley (*Hordeum vulgare*). Furthermore, major vegetable crops are onion (*Allium cepa*), garlic (*Allium sativum*), cabbage (*Brassica oleracea*), lettuce (*Lactuca sativa*), carrot (*Daucus carota*), and tomato (*Solanum lycopersicum*).

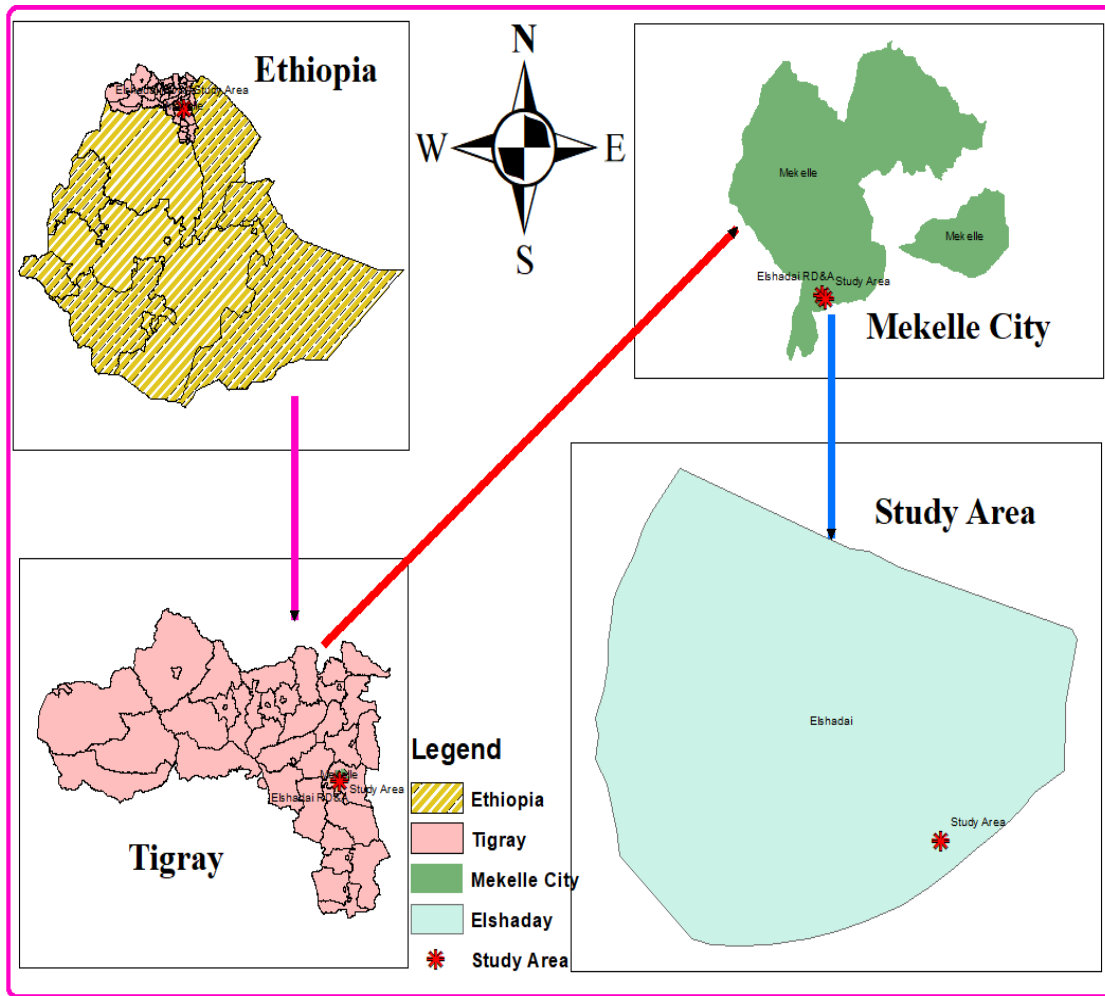


Figure 1: Location map of the study area

3.2. Experimental design and Treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD). Two factor treatments namely: Coated and uncoated of urea fertilizers and Four levels of Nitrogen. Nitrogen fertilizer rates were 0, 40, 80, and 120 kg/ha (Table 1) having 8 treatment combinations replicated four times. The size of each experimental plot was (2.4 m×2.8 m) and the spacing between plots and blocks was 1.0 m and 1.5 m, respectively. The spacing between rows was 0.70 cm, and tomato plants were transplanted at 0.3m distance between plants.

Table 3. 1 Treatment Combinations

Treatment	Coated and un coated	Nitrogen level
T1	Uncoated	0
T2	Uncoated	40
T3	Uncoated	80
T4	Uncoated	120
T5	Coated	0
T6	Coated	40
T7	Coated	80
T8	Coated	120

3.3. Experimental Materials and Procedure

Galilama tomato variety was grown as a test crop in the experimental site. The variety was obtained from local market and released year 2007 E C from Melkasa Agricultural Research Center (MARC). The experimental site was plowed by tractor to a depth of 30 cm which is the Common agricultural plow layer. Additionally, the experimental site was plowed twice by oxen before planting. Lastly, furrow preparation was carried out by daily laborers. The seedlings were raised on nursery beds and transplanted to the experimental plots after 45 days at a spacing of 30 cm between plant and 70 cm between rows. Thus, seedlings were watered to some extent immediately after transplanting uniformly to all the treatments. Here after, the seedlings were irrigated every 3 days for the first month. Subsequently, the plots were irrigated every 5 days interval until maturity.

Urea [$\text{CO}(\text{NH}_2)_2$] (46% N) and Triple Super Phosphate (45% P_2O_5) were used for the experiment as sources of nitrogen and phosphorus, respectively. Urea fertilizer was applied in split amounts, where half of the rate was applied at three weeks after the date of transplanting and the remaining half was applied at flowering stage as side dressing which was 10 cm far from plant rows (MoANR, 2016; Sigaye *et al.*, 2022). Triple super phosphate was applied at a rate of 200 kg ha⁻¹ uniformly at planting to fulfill the phosphorus requirement of the crop (Sigaye *et al.*,

2022; Wei *et al.*, 2024). A slow-release urea fertilizer coated with starch -bentonite clay was used for tomato production in this study. Coating of urea fertilizer was done using a fluidized bed coating with bentonite clay - starch as coating materials. The coating process and characterization of its behavior and optimization of the product was done in the Department of Chemical Engineering, Mekelle University. The optimized coated urea fertilizer was coated with bentoniteclay-starch. Bentonite clay and starch had a ratio of 25%, and 9%, respectively (Desbelom Weldegebrael, unpublished paper, 2025). All other agronomic practices were also carried out uniformly for all treatments according to recommendations for tomato.

3.4. Soil Sampling and Analysis

Soil sample at a depth of 0-30 cm was taken before planting from five random spots diagonally across the experimental field using auger. The collected soil samples were composited to one sample. The bulked soil samples collected before and after harvest were air dried, thoroughly mixed and ground to pass through 2 mm sieve. Then the samples were reduced to a working sample size of one kg by quartering method and properly labeled, packed and transported to the laboratory. Soil pH, soil organic carbon, soil organic matter (OM), texture (percent of clay, slit, and sand) total N, available phosphorous, potassium, and cation exchangeable capacity (CEC) were analyzed using the appropriate laboratory procedures at Mekelle University Soil Laboratory. The organic matter content was determined by the Walkley and Black procedure (Walkley and Black, 1934) method as described in Jackson (1967), The total nitrogen was determined using the Kjeldhal method as described in Jackson, (1976), The pH was measured in a 1:2.5 soil: water mixture suspension by using pH meter, Cation exchange capacity (CEC) in cmol (+) kg^{-1} was measured using ammonium acetate method (Jackson, 1967), Available

phosphorus was determined by the Olsen method (Olsen et al., 1954), Available potassium was determined with Morgan`s method (Gupta, 2000).

3.5. Data collection

Five plants were selected and considered from each plot for data collection. in Plant height (cm), number of branches plant⁻¹, fruit weight plant⁻¹ (kg), Number of fruit clusters plant⁻¹, fruit diameter (cm), fruit weight plot⁻¹ (kg), and Yield (kg ha⁻¹) were collected from the experimental plot.

Plant height (cm): The plant height was measured at the harvest time. The height of the plants was measured from the ground surface up to the tips of their longest leaves. Five randomly selected plants had their heights measured; the mean was computed and expressed in centimeters (cm).

Number of branches plant⁻¹: Five randomly selected plants per unit plot were used to calculate the average number of branches per plant.

Number of leaves plant⁻¹: Fully opened and matured leaves of tagged plants were counted and recorded at days 60 after transplanting.

Number of fruit clusters plant⁻¹: The numbers of fruit clusters per plant were counted at physiological maturity from randomly selected five plants. The average values were considered for analysis.

Fruit diameter (cm): The diameter (cm) of five fruits of varying sizes (very large, large, medium, small and very small) was collected from each selected plant. Diameters of each fruit were measured using a digital caliper. The mean diameter of a fruit was obtained by adding the

diameter of all the selected fruits and then dividing the sum by the number of selected fruits. The average values were used for the analysis.

Weight of single fruit (g): The weight of a single fruit (g) per plant was counted from selected plants of each treatment plant and then was weighed with the help of a highly sensitive electronic balance to record fruit weight per plant and was expressed in grams (g).

Fruit weight plot⁻¹ (kg): Fruit weight plot⁻¹ were counted from plants of each treatment plot and then were weighed with the help of highly sensitive electronic balance to record fruit weight plot-1 and was expressed in kilogram (kg).

Marketable fruit yield (kg ha⁻¹): Fruits their diameter was >2.5 cm and which were free of damage from the plot area were considered marketable at each harvest using a sensitive balance. The total marketable fruit yield is the sum of successive harvests.

Unmarketable fruit yield (kg ha⁻¹): Fruits thier diameter were ≤ 2.5 cm and which were damaged by insect, diseases, sun burn, cracked, and infected etc. from the plot area were considered as unmarketable yield. The total unmarketable fruit yield is the sum of successive harvests.

Total yield (kg ha⁻¹): The average total yield was obtained by adding marketable and unmarketable fruit yield.

3.6. Data analysis

The collected data were subjected to a two-way analysis of variance by using Gestat software version 18 for analysis of variance (ANOVA), and means comparisons for the significantly

different variables were made among treatments using the least significant differences (LSD) test at 0.05 levels of significance.

3.7. Nitrogen use efficiency

The nitrogen use efficiency (NUE) was used to evaluate the comparative benefits of the different treatment in enhancing the efficiency of N utilization by the crop. The nitrogen use efficiency was calculated as the ratio of the total tomato yield to the amount of Nitrogen applied (Congreves et al., 2021).

3.8. Economic Analysis

A simple cost and benefit analysis was performed to determine the profitability of tomato production through coating of different rates of urea treatments by using the procedures recommended by Interantional Maize and Wheat Improvement Center (CIMMYT 1988). Variable costs (cost of coated urea, cost of urea) and the benefit obtained from the sale of harvested tomato of the respective treatment were considered in the analysis. Tomato yield harvested from each treatment was reduced by 10 % in order to adjust the yield obtained from the expremental field (smaller field size and better crop management) to the yield that can be obtainable from the farmers' field. Under the research field relatively better crop management is performed than the farmers' field. In the economic analysis, the costs of coating, costs of coating material and urea were used as variable costs. Costs incurred for land preparation, planting, weeding, crop protection, and harvesting were assumed common to all treatments. All costs and benefits were calculated on hectare basis in Ethiopian Birr (1 Ethiopian Birr = 0.0087 USD based on exchange rates on September 1, 2024). The dominance analysis procedure as detailed in CIMMYT (1998) was also used to select profitable treatments from the range that were tested.

The marginal rate of return (MRR) was calculated by considering a pair of non-dominated treatments listed in the order of increasing net benefit.

$$\text{MRR (\%)} = 100 * (\Delta \text{NB} / \Delta \text{VC})$$

Where, the MRR is the marginal rate of return (%), NB is net benefit which: was calculated by subtracting the total variable costs from gross benefit.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Physical and Chemical Properties of Soil in the Experimental Site

The soil of the experimental site has a proportion of 49% sand, 17% silt and 34% clay (Table 4.1). According to the textural analysis, the soil is classified as sand clay loam. Based on the soil chemical analysis the pH is slightly acidic (6.42), and the organic matter is rated as low (0.97%).

Table 4.1 Major soil properties of the experimental site

Soil parameters	Unit	Value
Particle size distribution		
Sand	%	49
Silt	%	17
Clay	%	34
Textural class		Sand clay loam
Total N	%	0.13
Available P	Ppm	15.57
Available K	meq/100g soil	0.64
CEC	Meq/100g	24.5
Organic matter	%	0.97
pH		6.42

According to Tekalign (1991), soils having OM value in the range of 0.86-2.59% are considered as low and the pH value in the range of 6.0 - 6.6 are considered as slightly acidic. Srinivasan (2010) reported that the optimal soil pH for tomato production is 6.0-7.5, and hence the soil was conducive for tomato cultivation. The cation exchange capacity at the soil depth from 0 to 30 cm is medium (24.5 Meq/100gm). According to Hazelton and Murphy(2007) CEC of the experimental area falls under medium category (Appendix 3). Cation exchange capacity (CEC) describe the potential fertility of the soils. Total nitrogen was very low (0.13%), available P

(15.57PPm) and Available potassium (0.64 Meg soil) were very low. According to FAO (2006), soils having available P between 15-30 ppm is categorized as medium. As described in Table 4.1, available K of 0.64 is rated as medium (Horneck *et al.*,2011).

4.2 Effects of Coated Different Rates of Urea on Growth, Yield and Yield Component of Tomato

4.2.1. Effects on Plant height

The statistical analysis of variance showed significant ($p < 0.05$). effect on the coated urea and nitrogen level. The tallest (80.25 cm) and the shortest (51.65- 40.37cm) tomato plant heights were recorded from the coated urea with the 120 kg Nitrogen and the control plot, respectively (Table 4.2).

Table 4.2 Effect of urea coating and different level of nitrogen fertilizer on tomato plant height, number of branch per plant and number of leaves per plant.

Treatments		Growth parameters		
Coating	Rate of N (kg ha ⁻¹)	Plant height (cm)	Number of branch per plant	Number of leaves per plant
Uncoated	0	51.65d	2.7e	53.95d
	40	59.70c	3.575d	62.9c
	80	65.72b	4.150c	68.62b
	120	70.05b	4.850b	70.85b
Coated	0	55.20 cd	3.00e	54.25d
	40	68.12b	4.7b	69b
	80	77.47a	5.5a	78.50a
	120	80.25a	5.35a	77.55a
	P-value	0.010	<0.001	0.006
	LSD	3.346	0.3583	2.931
	CV (%)	3.4	5.8	3

Key: T1 =uncoated urea with 0 Nitrogen level, T2= uncoated urea with 40 nitrogen level, T3 = uncoated urea with 80 Nitrogen level, T4=uncoated urea with 120 Nitrogen level, T5=coated urea 0 Nitrogen, T6 = coated urea with 40 Nitrogen level, T7=coated urea with 80 Nitrogen level, T8=coated urea with 120 Nitrogen level

**Significant at 1% probability level, * Significant at 5% probability level, LS= Level of significance, and CV= Co-efficient of variance, coating material bentonite clay and starch.

Plant height generally increased with all coated fertilizer treatments compared to the uncoated urea treatment indicating that coated urea may improve nutrient availability and uptake in an extended period of time. The application of 40 kg ha⁻¹ coated urea was showed statistically similar effect with the application 120 kg Nha⁻¹ of uncoated urea. This indicates that coated urea was more effective way of N fertilizer application for promoting plant growth. This study was in line with the finding of Nie *et al.* (2022), who reported that the Polymer-Coated Urea increased plant height by 10% to 30% over conventional application of Nitrogn.

4.2.2. Effects on number of branches plant

The effect of coated urea and nitrogen level were highly significant ($P < 0.001$) on number of branches per plant (Table 4.2). Among the treatment combinations, coated urea with 120 kg Nha⁻¹ showed the highest number of branches per plant (6.5 branches). This increased branching can lead to a more strong plant structure, which is essential for supporting fruit development. In contrast, the control treatments resulted in afew number of branches per plant (2.7-3.8 branches), indicating that insufficient nitrogen availability limits branching potential. Coated urea signifcately treatment increased 32.5% on number of branches per plant over uncoated urea treatments. This result was also in agreement with the finding of Tubeileh, .2023) who reported that Polymer-Coated urea at 100 kg N/ha⁻¹ increased number of branch per plant in maize.

4.2.3. Effects on number of leaves per plant

The number of leaves plant⁻¹ was significantly ($P < 0.001$) influenced by the coated urea and nitrogen level (Table 4.2). (coated urea with 120 kg Nha⁻¹ showed the highest number of leaves plant⁻¹ (79 leaves) and the lowest number leaves plant⁻¹ (54-54.25 leaves) was observed from plots with control (Table 4.2). The results of this study indicate that higher nitrogen levels,

particularly when applied in the form of coated urea, enhanced vegetative growth in tomato plants. The significant increase in leaf number per plant is crucial, as a greater leaf area enhances photosynthetic capacity, ultimately contributing to improved plant vigor and yield potential. This study was in line with the finding of Olowoake *et al.* (2024), who reported that neem coated urea at 100 kg N/ha increased number of leaves in maize.

4.2.4. Effects on Weight of Single Fruit (gm)

The weight of a single fruit was significantly influenced by the main effects of coating of urea fertilizer and different levels of nitrogen. The interaction effect of coated and nitrogen levels is also very highly significant ($P < 0.001$) (Table 4.3). Among the treatment combinations, the highest weight of a single fruit (185-187 g) was observed from plots treated with coated urea with 80 kg Nha^{-1} and with 120 kg Nha^{-1} . On the contrary, the lowest weight of a single fruit (82.0g) was observed from control for the uncoating and coating of urea, respectively. This indicates that the combination of coated urea and optimal nitrogen levels not only enhances the quantity of fruit but also increases their size and marketability.

4.2.5. Effects on number of fruit cluster per plant

The number of fruit cluster per plant was significantly influenced by the application of coated urea and different levels of nitrogen fertilizer (Appendix Table 2). The interaction effect of urea coating and nitrogen level was also significant ($P < 0.05$) (Table 4.3). This shows that the highest number of fruit clusters $plant^{-1}$ (19.0-19.47) was recorded in plots treated with coating of urea having rates of 80 kg N and 120 kg N, respectively, whereas the lowest number fruit cluster $plant^{-1}$ (7.30-8.65) were observed from the control treatments for the uncoating and coating of urea (Table 3).

4.2.6. Effects on Fruit Diameter (cm)

The analysis of variance showed highly significant ($p < 0.001$) effect of coating of urea and the different levels of nitrogen on tomato fruit diameter (Table 4.3). Coating of urea performed significantly better in fruit diameter than the uncoating treatments, With regard to the nitrogen levels, all the nitrogen application showed higher fruit diameter than the control within the category of coating and uncoating of urea. The highest fruit diameter (6.8cm) was found in the treatment coated with 120kg N followed by coated with 80kg N. However the minimum fruit diameter (5.225-5.42 cm) was observed from treatments Control.

Table 4.3 Effect of urea coating and different level of nitrogen fertilizer on tomato fruit diameter, number of fruit clusters plant¹, weight of single fruit

Treatments		Yield component parameters		
Coating	Rate of N (kg ha ⁻¹)	Weight of Single Fruit (g)	Number of fruit clusters plant-1	Fruit diameter (cm)
Uncoated	0	81.8e	7.30 e	4.23c
	40	110d	10.55 d	5.0bc
	80	143c	12.40 c	5.21b
	120	156.7b	15.67 b	5.53b
Coated	0	81.6 e	8.65 de	4.82cd
	40	152b	16.35 b	6.698a
	80	187a	19.47 a	6.795a
	120	185a	18.75 a	6.80 a
	P-value	<0.001	0.002	0.001
	LSD	7.214	1.840	0.724
	CV (%)	3.6	9.1	7.9

Key: T1 =uncoated urea with 0 Nitrogen level, T2= uncoated urea with 40 nitrogen level, T3 = uncoated urea with 80 Nitrogen level, T4=uncoated urea with 120 Nitrogen level, T5=coated urea 0 Nitrogen, T6 = coated urea with 40 Nitrogen level, T7=coated urea with 80 Nitrogen level, T8=coated urea with 120 Nitrogen level
 **Significant at 1% probability level, * Significant at 5% probability level, LS= Level of significance, and CV= Co-efficient of variance, coating material bentonite clay and starch.

4.2.7. Effects on Yield

The main effects of coating of urea and the different nitrogen levels, and their interaction effect on marketable, unmarketable and total tomato yield were highly significant (Appendix Table 3). The highest marketable tomato fruit productivity (68,118-67,783 kg/ha) was recorded from plots treated with coated urea having 120 and 80 kg N per ha (Table 4.4). This treatment not only produced the highest marketable fruit yield but also maintained a relatively low level of unmarketable fruit (6,176-6,473kg ha^{-1}).

Table 4.4 Effect of coated and uncoated urea with different level of nitrogen on yield of tomato marketable fruit, unmarketable fruit, and total yield.

Treatments		Yield parameters			
Coating	Rate of N (kg ha ⁻¹)	Marketable (kg/ha)	fruit	Un marketable fruit (kg/ha)	Total yield (kg/ha)
Uncoating	0	35082d		5097b	40179d
	40	40365 c		6473b	46838c
	80	53943b		8780a	62723b
	120	55804 b		10007a	65811b
Coating	0	34896 c		5655 b	40551d
	40	59077 b		8208 b	64286b
	80	67783 a		6473 b	74256a
	120	68118a		6176b	74293a
	P-value	<0.001		0.001	0.003
	LSD	4946.9		1408.6	4870.4
	CV (%)	6.4		14.1	5.6

Key: T1 =uncoated urea with 0 Nitrogen level, T2= uncoated urea with 40 nitrogen level, T3 = uncoated urea with 80 Nitrogen level, T4=uncoated urea with 120 Nitrogen level, T5=coated urea 0 Nitrogen, T6 = coated urea with 40 Nitrogen level, T7=coated urea with 80 Nitrogen level, T8=coated urea with 120Nitrogen level. **Significant at 1% probability level, * Significant at 5% probability level, LS= Level of significance, and CV= Co-efficient of variance, coating material bentonite clay and starch.

This indicates that coated urea effectively improves plant growth, fruit development, and minimizing losses. Conversely, lower marketable fruit (35,082-34,896 kg ha⁻¹) was produced

from plots that were not treated with N. This stark contrast underscores the critical role of nitrogen in achieving viable tomato production. Generally total tomato yield, comprising both marketable and unmarketable, was highest under the coated urea fertilizer.

The effect of urea coating and nitrogen levels on total yield was significant ($P < 0.05$). The highest yield ($74,293 \text{ kg ha}^{-1}$) was observed from the application of coated urea with 120 kg N ha^{-1} and this was followed by the coated with 80 kg N treatment, and the lowest total yield ($40,179\text{-}40,551 \text{ kg ha}^{-1}$) was observed from the control treatments. The differences between the coated and uncoated urea treatments were significant, where coated urea fertilizer showed 25-27% higher yield compared to uncoated urea. Application of 40 kg N ha^{-1} , 80 kg N ha^{-1} , and 120 kg N ha^{-1} , with formulation of coated urea, consistently produced higher yields compared to their uncoated treatments at similar nitrogen levels. Coated urea with 40 kg N ha^{-1} yielded $64,286 \text{ kg total tomato yield ha}^{-1}$, while uncoated urea with the same nitrogen level yielded only $46,838 \text{ kg ha}^{-1}$. This indicates that the use of coated urea fertilizers enhances nutrient availability and uptake, likely due to their slow-release properties, which help to reduce nitrogen leaching and increase nutrient retention in the soil. This study was in line with the finding of (Mao et al., 2024), who reported that Coated urea fertilizer significantly increased tomato yield by 25.2% compared to conventional fertilizer treatments and reduced nitrogen leaching, thereby enhancing nitrogen use efficiency.

4.3. Effect of Coating and Different Rates of Urea on Nitrogen Use Efficiency (NUE)

The NUE values calculated for each treatment indicate that coated urea fertilizers, particularly at lower nitrogen levels, resulted in impressive efficiency in nitrogen utilization. coated urea with 40 kg N ha^{-1} exhibited the highest NUE, 1,607.15 (Table 4.5), suggesting that this treatment

achieved substantial yields with relatively low nitrogen input. This finding indicates the potential of coated fertilizers to enhance nitrogen absorption and utilization, likely due to their slow-release that took place in the extended period of time in the crop growing cycle which provided a more steady supply of nutrients to the plants.

Table 4.5 Effect of coated and uncoated urea with different level of nitrogen on NUE of tomato

Nitrogen Level (kg/ha)	Uncoated Urea (NUE)	Coated Urea (NUE)	Percentage Increase in NUE (%)
0	-	-	-
40	1170.95	1607.15	37.2%
80	784.04	927.00	18.2%
120	548.43	619.11	12.9%

In contrast, treatments with higher nitrogen levels and with no coating of urea (uncoated urea with 120 kg N/ha⁻¹), had lower NUE values (548.43). Even though higher nitrogen inputs initially boost yields, the returns in terms of NUE diminished as nitrogen levels increase. Such diminishing returns highlight the importance of optimizing nitrogen application rates to achieve maximum efficiency and minimize excess nitrogen that could lead to environmental concerns, such as leaching and runoff.

Coated urea shows a significant improvement in NUE. In comparison with the uncoating, coating of urea especially at the lower nitrogen levels (at 40 kg N/ha, increased NUE efficiency by 37.2%. This study was in line with the finding of Zhu *et al.* (2018) who reported that the use of polymer-coated urea improved NUE by 15-25% in wheat and maize crops, compared to conventional urea application.

4.4. Economic analysis

Table 4.6 shows, total and adjusted tomato yield, total variable cost, gross and net benefit earned from the different treatment combinations of urea coating and N levels tested in the study area.

Table 4. 6 Total yield, adjusted yield, variable cost, and net benefit of the combinations of coating of urea and N levels

Trt	Adj. Yield (kg/ha)	Gross benefit (Birr/ha)	Variable cost (Birr/ha)	Net benefit (Birr/ha)
T1	36,161.1	1,084,833.00	21,200	1,084,833.00
T2	42,154.2	1,264,626.00	26,420	1,259,406.00
T3	56,450.7	1,693,521.00	31,640	1,683,081.00
T4	59,229.9	1,776,897.00	36,860	1,761,207.00
T5	36,495.9	1,094,877.00	23,500	1,094,877.00
T6	57,857.4	1,735,722.00	29,030	1,727,892.00
T7	66,830.4	2,004,912.00	36,860	1,989,252.00
T8	66,863.7	2,005,911.00	44,690	1,982,421.00

Key: T1 =uncoated urea with 0 Nitrogen level, T2= uncoated urea with 40 nitrogen level, T3 = uncoated urea with 80 Nitrogen level, T4=uncoated urea with 120 Nitrogen level, T5=coated urea 0 Nitrogen, T6 =coated urea with 40 Nitrogen level, T7=coated urea with 80 Nitrogen level, T8=coated urea with 120 Nitrogen level

Among the 8 treatment combinations tested, 2 treatments (T3 and T8) were dominated and excluded from the marginal analysis (Table 4.7).

Table 4.7. Dominance analysis of the combinations of coating of urea and N level

Trt	AJY	GB	TVC	NB	D	MC	MB	MRR%
T1	36161.1	1084833.00	21,200	1084833.	-	21,200	1084833	5117
T5	36495.9	1094877.00	23,500	1094877	-	2,300	10044	436.6
T2	42154.2	1264626.00	26,420	1259406	-	2,920	164529	5,634.66
T6	57857.4	1735722.00	29,030	1727892	-	5,220	468486	8,974.8
T3	56450.7	1693521.00	31,640	1683081	D		-	-
T4	59229.9	1776897.00	36,860	1761207	-	7830	33315	425.4
T7	66830.4	2004912.00	36,860	1989252	-	0	228045	-
T8	66863.7	2005911.00	44,690	1982421	D			

Key: T1 =uncoated urea with 0 Nitrogen level, T2= uncoated urea with 40 nitrogen level, T3 = uncoated urea with 80 Nitrogen level, T4=uncoated urea with 120 Nitrogen level, T5=coated urea 0 Nitrogen, T6 =coated urea with 40 Nitrogen level, T7=coated urea with 80 Nitrogen level, T8=coated urea with 120 Nitrogen level

In comparison with the control treatment (T1=uncoated urea with no N application), 40 kg N ha⁻¹ with uncoated urea offered a MRR of 5,634.66% (= a return of 31.519 Birr for each 1 Birr investment in the treatment). In comparison with uncoating, coating of urea gave extra return. When compared with T2, the application 40 kg N ha⁻¹ in a coated urea (T6) gave a MRR of 8,974.8%. Coating of urea was the only difference between T2 and T6, indicating that coating of urea was the most profitable.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The application of bentonite clay- starch-coated urea fertilizers significantly improved plant growth and growth parameters, including plant height, number of branches, number of leaves, and weight of single fruits and yield. The treated plants showed enhanced nutrient availability and uptake, which led to increased tomato yield and nitrogen use efficiency compared to uncoated urea treatments. The experimental results indicated that the optimal nitrogen levels for bentonite clay and starch-coated urea fertilizers were 40 kg/ha which provided substantial improvements in yield parameters. The use of coated urea fertilizers not only increased crop productivity but also reduced nitrogen losses, thereby offering economic benefits through efficient nitrogen management. Coating of urea with bentonite clay-starch generally offered higher tomato production and profitability. Among the different coated urea treatments, application of 40 kg N ha⁻¹ gave the highest profitability. These findings support the adoption of coated fertilizers as a sustainable and economically viable solution for improving tomato production and addressing food security challenges.

5.2. Recommendation

Based on the findings of this study, the following recommendations are suggested:

It is recommended to use nitrogen levels of 40 kg ha⁻¹ for coated urea fertilizers, as these levels have shown significant improvements in tomato yield and profitability.

Since the study was conducted in one location and one season, similar studies should be conducted to explore the long-term effects of bentonite clay - starch-coated urea fertilizers on soil health and crop productivity. Additionally, research should investigate the applicability of these fertilizers in different places and for different seasons to validate the findings.

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7. Appendix

Appendix Tables

Appendix Table: 1 analysis of variance for the main and interaction effects of coating of urea, and different rates of N (urea) fertilizer on tomato plant height, number of branches per plant and number of leaves per plant

Source	DF	Mean Squares					
		Plant height (cm)	Prob.	No. of branches plant ⁻¹	Prob.	No. of leaves plant ⁻¹	Prob.
Replication	3	3.49		0.01698		74.969	
Urea(coated and un coated)	1	783.09	<.001	5.36281	<.001	299.513	<.001
Nitrogen level	3	628.93	<.001	8.06365	<.001	649.473	<.001
Coating * N level	3	48.63	0.01	0.49781	<.001	22.066	<0.001
Error	21	10.05		0.05936		3.972	
Total	31						

Appendix Table: 2 analysis of variance for the main and interaction effects of coating of urea, and different rates of N (urea) fertilizer on weight of single fruit, number of fruit clusters per plant and fruit diameter

Source	DF	Mean Squares					
		Weight of single fruit (gm)	Prob.	No. of fruit clusters plant ⁻¹	Prob.	Fruit Diameter (cm)	Prob.
Replication	3	8.91		1.461		0.0800	
Urea(coated and un coated)	1	7269.17	<.001	162.000	<.001	3.0197	0.010
Nitrogen level	3	12636.67	<.001	123.449	<.002	1.9185	0.001
Coating * N level	3	649.40	<.001	10.902	0.001	0.1473	0.001
Error	21	24.67		1.575		0.2425	
Total	31						

Appendix Table: 3. analysis of variance for the main and interaction effects of coating of urea, and different rates of N (urea) fertilizer on tomato marketable yield, unmarketable yield and total yield

Source	DF	Mean Squares					
		Marketable fruit (kg/ha)	Prob.	Unmarketable fruit (kg/ha)	Prob.	Total yield (kg/ha)	Prob.
Replication	3	1.429E+08		0.3703		1.536E+08	
Urea(coated and un coated)	1	1.100E+09	<.001	9.1378	<.001	8.222E+08	<.001
Nitrogen level	3	1.161E+09	<.001	5.6228	<.001	1.393E+09	<.001
Coating * N level	3	9.822E+07	<.001	3.7845	0.001	7.188E+07	0.003
Error	21	1.132E+07		0.4144		1.097E+07	
Total	31						

Appendix Table: 4 Total cost

Fertilizer cost	Land preparation	Transplanting	Field mgt	chemical	Harvesting	Total variable cost	
T1	0	6000	2000	9000	750	3450	21,200
T2	5220	6000	2000	9000	750	3450	26,420
T3	10440	6000	2000	9000	750	3450	31,640
T4	15,660	6000	2000	9000	750	3450	36,860
T5	2300	6000	2000	9000	7500	3450	23,500
T6	7830	6000	2000	9000	750	3450	29,030
T7	15660	6000	2000	9000	750	3450	36,860
T8	23,490	6000	2000	9000	750	3450	44,690