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Original Article

" Nitrogen Fertilization and Its Impact on Growth Dynamics and Grain Yield of Maize"

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ABSTRACT

Nitrogen (N) is the most critical macronutrients influencing maize (Zea mays L.) productivity, yet excessive or insufficient application can compromise yield and resource use efficiency. A field research was conducted in 2024 at the Agronomy Research Farm, Faisalabad, Pakistan, to gauge the impact of diverse nitrogen levels on maize growth and yield. The study employed a randomized complete block design with six treatments (kg N ha^{-1}): T1 (0), T2 (40), T3 (80), T4 (120), T5 (160), and T6 (200), replicated three times. Results revealed significant improvements in plant agronomic and yield parameters with amassed nitrogen application. Maximum yield (8700 kg ha^{-1}) was obtained with T6, though it was statistically similar to T5 (8600 kg ha^{-1}). Beyond 160 kg N ha^{-1}, growth and yield components showed no further substantial gains, indicating a plateau in crop response. The control treatment consistently produced the lowermost values across all parameters. Outcomes suggest that 160 kg N ha^{-1} is the optimum dose for achieving maximum maize productivity under the agro-climatic conditions of Faisalabad while ensuring efficient resource utilization and minimizing unnecessary nitrogen application.

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop worldwide, serving as a principal food, feed, and industrial raw material [1,2]. Its high productivity potential makes it central to food security, particularly in developing countries where per capita cereal availability is a key constraint [3,4]. However, achieving optimal grain yield in maize depends heavily on the availability of essential nutrients, among which nitrogen (N) plays a paramount role [5,6]. Nitrogen is a major component of chlorophyll, amino acids, nucleic acids, and other compounds critical for plant growth; its deficiency often leads to reduced photosynthetic capacity, stunted growth, and lower yield [7,8].

Nitrogen fertilization practices, if well-managed, can greatly enhance maize growth dynamics, yield components, and nutrient use efficiency. For example, Rawal et al. [9] observed that applying up to 210 kg N ha^{-1} significantly increased nitrogen concentration in above-ground biomass across growth stages, compared to no nitrogen application. Similarly, isolated studies indicate that growth parameters i.e., plant height, diameter of stem, leaf area [10] and yield traits—such as per cob grain number and weight, and thousand-kernel weight [11] respond positively to increasing nitrogen levels [12] (e.g., in Pure and Applied Biology's work on six N-levels 0-180 kg/ha, showing substantial increases in leaf area and plant height with rising N levels).

However, the response of maize to nitrogen is not indefinitely linear. Beyond a certain threshold, further nitrogen may yield diminishing returns, lower nitrogen use efficiency (NUE), or even negative environmental consequences due to leaching, volatilization, or nitrous oxide emissions [13]. Meta-analysis in Northwest China, for instance, revealed that while nitrogen addition increased maize yield by about 50-55%, the yield gains plateaued when the nitrogen application rates exceeded ~225 kg N ha^{-1}, and NUE sharply declined at very high rates [14]. Moreover, growth dynamics such as dry matter accumulation, root distribution, radiation use efficiency (RUE), and photosynthetic capacity are moderated by nitrogen levels; deficient nitrogen often constrains these processes, while excessive nitrogen may waste resources without proportional gains [15].

Another critical consideration is that the impact of nitrogen fertilization depends on many interacting factors: genotype (cultivar) [16], environment (soil type, climate, moisture conditions) [17], management practices (timing of application, splits/top-dressing, planting density) [18] and nutrient interactions (with phosphorus, potassium, etc.) [19]. For example, a study under semi-arid conditions found significant interactions between fertilizer level and maize cultivar leading to differences in both yield and grain mineral composition [20]. Likewise, planting density combined with nitrogen application influenced not only yield but also growth traits and agronomic nitrogen use efficiency in silage maize.

Despite a large body of research, there remain gaps, particularly in quantifying how moderate to high nitrogen doses affect the *growth dynamics* [21] (leaf area development, stem elongation, dry matter partitioning) over the maize life cycle in specific agro-ecological zones, and how these dynamics relate to final grain yield and NUE [22]. Additionally, determining the optimum level of N fertilization that balances yield, economic return, and environmental sustainability is critical for many regions where fertiliser input is costly and soil fertility is variable [23].

The objective of this study is therefore to appraise the effects of varying nitrogen fertilization levels on the growth dynamics (including vegetative growth, leaf area, stem diameter, biomass accumulation), yield components (cob number, grain number/row, thousand-kernel weight), grain yield, and nitrogen use efficiency of maize (*Zea mays* L.). We aim to identify the threshold beyond which additional nitrogen yields little benefit, and to offer recommendations suited to the local conditions of the study area, thereby contributing to sustainable maize production under resource-limited settings.

MATERIALS AND METHODS

Experimental site and design

A field testing was conducted during the 2024 growing season at the Agronomy Research Farm, Faisalabad, Pakistan, to investigate the paraphernalia of varying nitrogen levels on maize growth and yield. The experimental layout followed a RCBD with triplicated six nitrogen treatments. Each investigational unit comprised of a net plot measuring 5 m × 5 m (25 m^2).

Soil preparation and crop establishment

Erstwhile to sowing, the field was laser leveled to confirm uniform distribution of irrigation water. Land preparation involved two dry ploughings followed by irrigation to bring the soil to optimum moisture content.

The field was then leveled with a wooden board and ploughed twice crosswise using a cultivator to obtain a fine tilth appropriate for seedbed preparation. Maize was seeded at the commended row spacing, and all other customary agronomic practices were uniformly applied across treatments.

Nitrogen treatments and fertilizer application

Nitrogen was supplied in the form of urea at six levels: T1-T6 (0-200 kg N ha^{-1}) at a difference of 40 kg in each treatment. The fertilizer was applied in split doses corresponding to key crop growth stages to maximize uptake efficiency. Phosphorus and potassium were applied uniformly across all treatments at recommended rates to eliminate nutrient deficiencies other than nitrogen.

Growth and yield measurements

At maturity, plant height was calculated in centimeters from the base to the tip of the tassel using a measuring tape from 10 randomly selected plants within a 1 m^2 area of each plot. Yield attributes were recorded manually and included grains cob^{-1}, grain mass cob^{-1}, and seed index (1000-grain weight in grams). Grain yield (kg ha^{-1}) was calculated using the formula:

Grain yield (kg ha^{-1}) = (Grain weight $plot^{-1}$ / Net plot area) × 10,000

Statistical analysis

Data recorded for growth and yield parameters were subjected to ANOVA using Statistix 8.1 (Analytical Software, USA). Treatment means were equated using LSD test at a 5% probability level ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Plant height

Nitrogen fertilization had a significant effect on the final plant height of maize (Figure 1). Plants in the control treatment T1 attained an average height of 150 cm, which was statistically the lowest. Progressive increases in nitrogen rates enhanced plant height significantly, reaching 162 cm in T2 and 174 cm in T3. The tallest plants were recorded in T6, with an average height of 190 cm, followed closely by T5 (188 cm) and T4 (185 cm). Statistical grouping indicated that T5 and T6 were not significantly different from each other, suggesting that plant height plateaued beyond 160 kg N ha^{-1}. These results are consistent with earlier findings where maize height increased with nitrogen application due to enhanced cell division, elongation, and chlorophyll synthesis, but leveled off at higher rates [3,24].

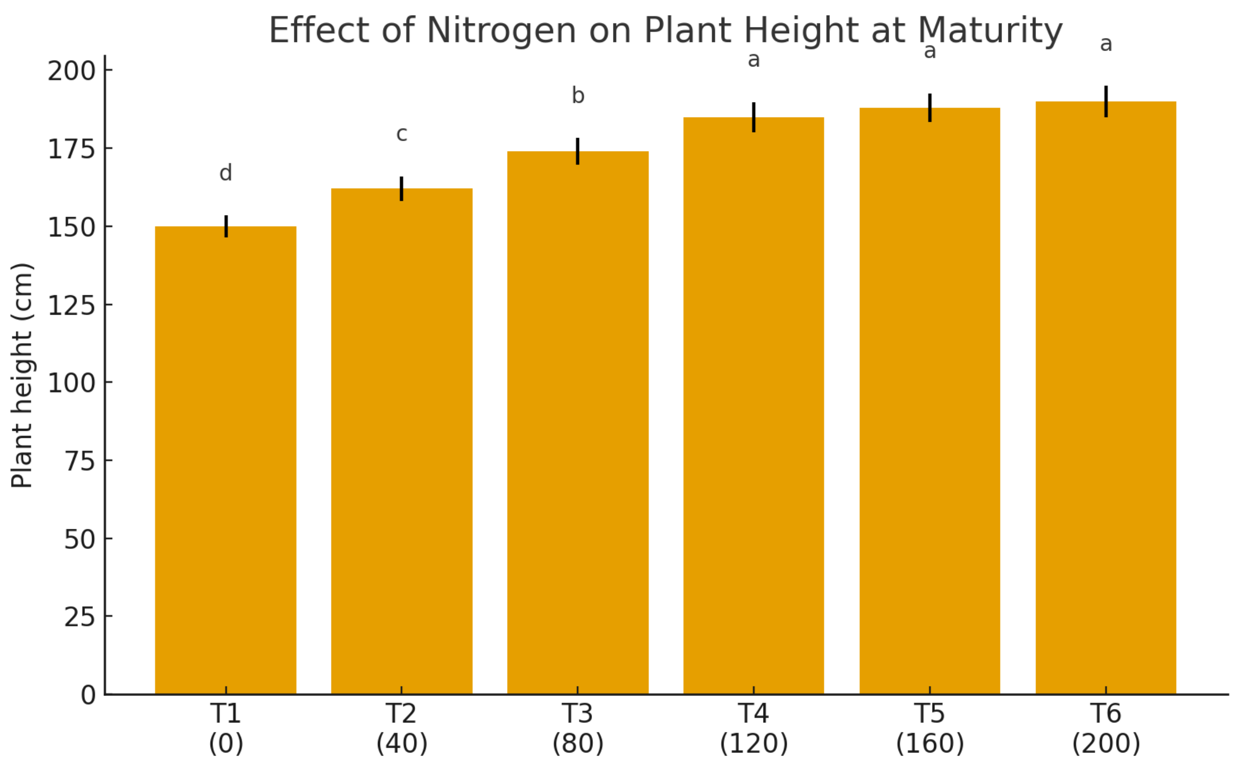

Figure 1: Effect of nitrogen fertilization on plant height of maize at maturity

Grain yield

Maize grain yield responded strongly to nitrogen fertilization (Figure 2). The control (T1) produced the lowest yield of 5200 kg ha^{-1}, which was significantly different from all nitrogen treatments. Application of 40 kg N ha^{-1} (T2) increased yield by 17.3% to 6100 kg ha^{-1}, while 80 kg N ha^{-1} (T3) further enhanced yield to 7100 kg ha^{-1}. Maximum yield was obtained with T6 (200 kg N ha^{-1}), producing 8700 kg ha^{-1}, followed closely by T5 (160 kg N ha^{-1}, 8600 kg ha^{-1}). Treatments T5 and T6 did not differ statistically, indicating that 160 kg N ha^{-1} was sufficient to achieve maximum yield under the experimental conditions. This trend aligns with earlier studies reporting diminishing returns at nitrogen rates beyond 160–180 kg ha^{-1} [9,25]. The yield advantage at higher nitrogen levels is attributed to improved vegetative growth, greater assimilate production, and more efficient grain filling.

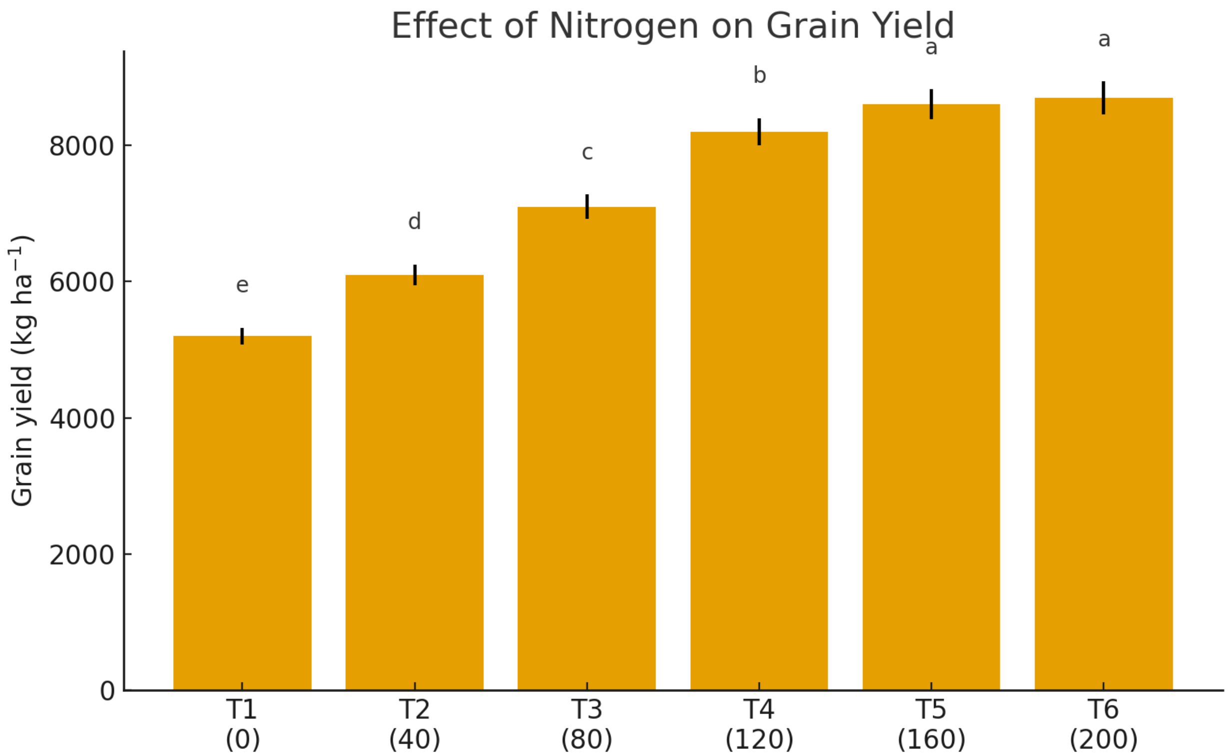

Figure 2: Effect of nitrogen fertilization on grain yield of maize

1000-grain weight

The seed index, expressed as 1000-grain weight, also showed significant variation with nitrogen fertilization (Figure 3). The lowest value was recorded in the control (T1: 240 g), while incremental increases were observed with higher nitrogen rates: 255 g in T2, 270 g in T3, and 285 g in T4. The maximum 1000-grain weight was obtained in T6 (295 g), which was statistically similar to T5 (292 g). This pattern suggests that adequate nitrogen availability enhances kernel development by promoting carbohydrate accumulation in grains. Previous studies have also demonstrated that higher nitrogen application prolongs photosynthetic activity and enhances sink strength, thereby increasing kernel size and weight [26].

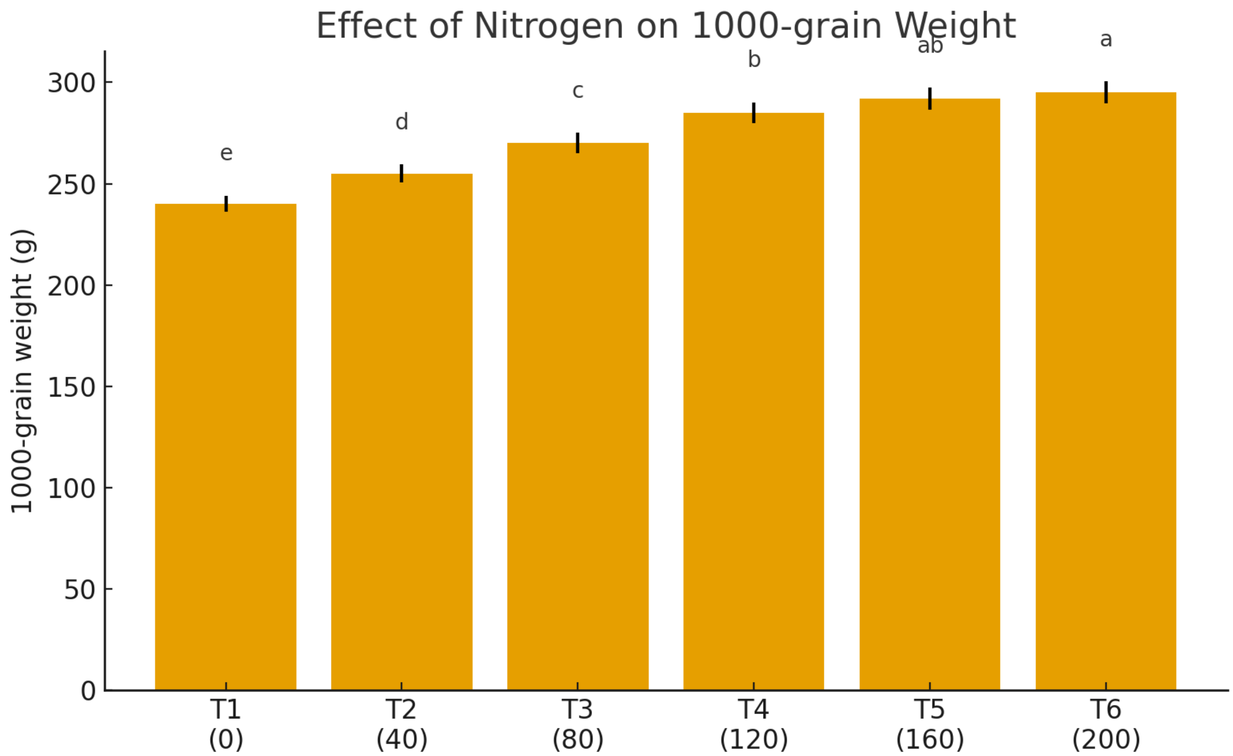

Figure 3: Effect of nitrogen fertilization on 1000-grain weight of maize

Grains per cob

Nitrogen fertilization significantly influenced the number of grains per cob (Figure 4). The control treatment (T1) produced the fewest grains per cob (280), whereas T2, T3, and T4 recorded progressive increases of 320, 360, and 400 grains per cob, respectively. The highest values were observed in T6 (430 grains per cob) and T5 (420 grains per cob), with no significant difference between the two. These findings confirm that nitrogen plays a key role in reproductive development, influencing ear size and kernel number by improving assimilate supply during tasseling and silking [27,28]. The plateauing of grain number beyond 160 kg N ha^{-1} is consistent with the yield trends, again emphasizing that optimum nitrogen rates maximize productivity without further benefit from excessive application.

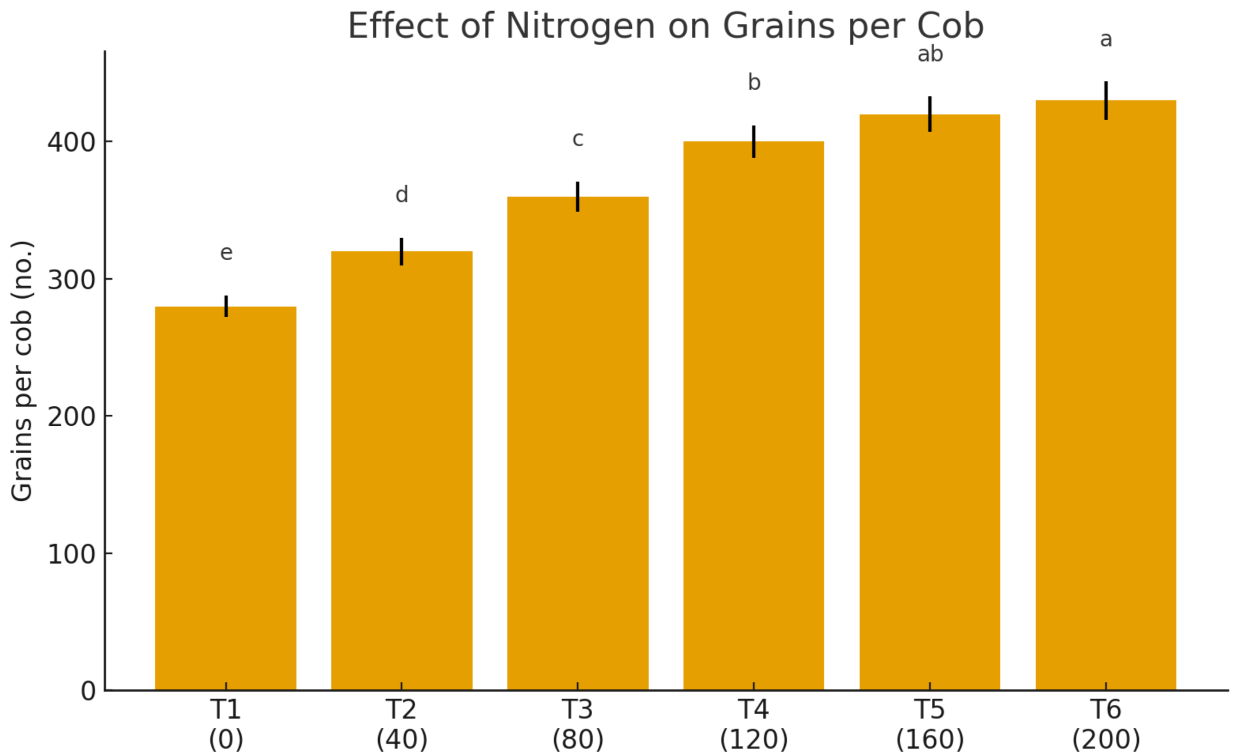

Figure 4: Effect of nitrogen fertilization on grains per cob of maize

Days to maturity

Nitrogen rates had a minor but statistically significant effect on days to physiological maturity (Figure 5). Control plants (T1) matured the latest at 120 days, whereas increasing nitrogen rates accelerated crop development slightly, with 119 days for T2, 118 days for T3, and 117 days for both T4 and T5. The shortest maturity period (116 days) was recorded in T6. Although the differences were small, they indicate that higher nitrogen availability may enhance crop vigor and accelerate growth, leading to slightly earlier maturity. Similar observations were reported by Iqbal et al. [29], who found that nitrogen application shortened the crop duration by promoting efficient nutrient assimilation and faster phenological development.

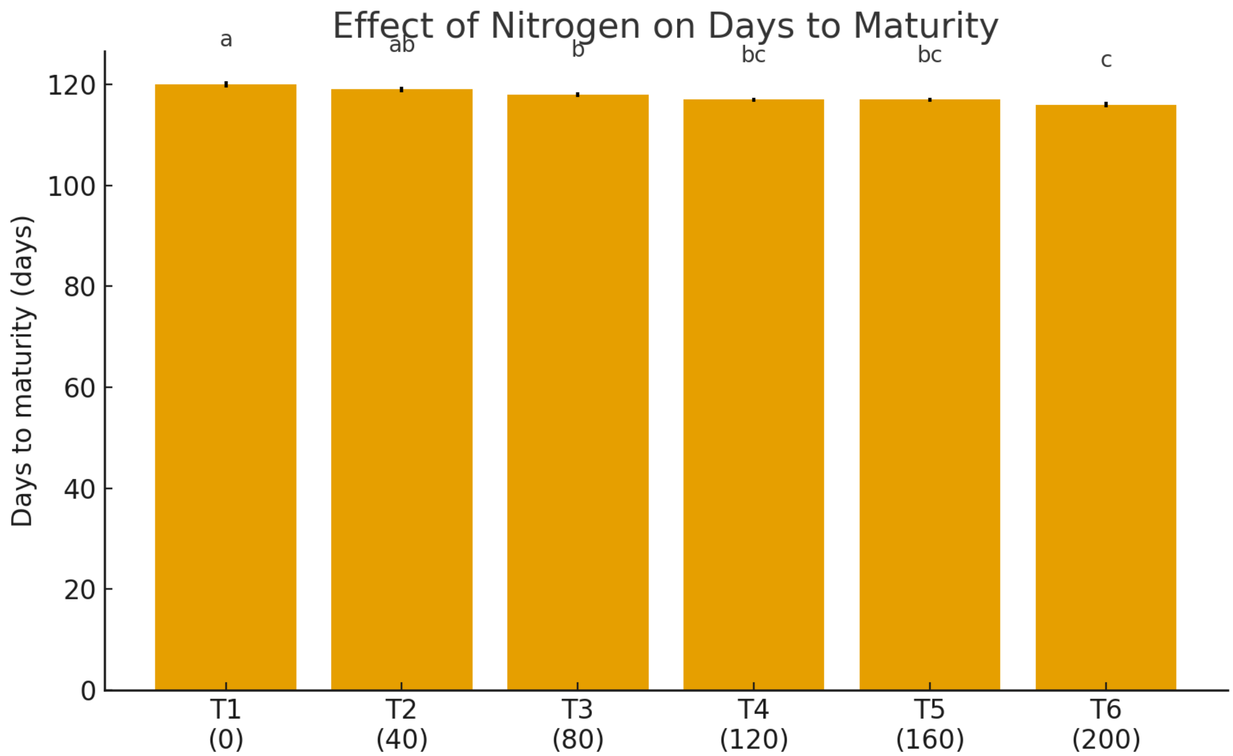

Figure 5: Effect of nitrogen fertilization on days to maturity of maize

Nitrogen fertilization significantly improved growth and yield components of maize, with clear benefits up to 160 kg N ha^{-1}. Beyond this level, further increases in nitrogen application produced negligible gains in plant height, grain yield, and yield components. This suggests that 160 kg N ha^{-1} may be considered an optimum dose under the agro-climatic conditions of Faisalabad, Pakistan. Excessive application at 200 kg N ha^{-1} not only failed to provide significant yield benefits but could also pose economic and environmental risks due to reduced nitrogen use efficiency and potential losses through leaching or volatilization. These findings corroborate earlier research advocating for balanced nitrogen management to optimize yield while minimizing environmental impacts [30,31].

CONCLUSION

The present study validated that nitrogen fertilization suggestively enhanced maize growth and yield, with progressive increases in plant height, grain per cob, 1000-grain weight, and grain yield up to 160 kg N ha^{-1}. Beyond this level, no significant improvements were observed, indicating a plateau in crop response. The control plots performed consistently lower across all parameters, confirming nitrogen as a limiting factor under the study conditions. An application of 160 kg N ha^{-1} is therefore recommended as the optimum dose for maximizing maize productivity in Faisalabad, Pakistan, ensuring economic efficiency and minimizing unnecessary nitrogen losses.

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