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Effect of Split Application of Nitrogen on Growth and Yield of Maize

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Abstract
Nitrogen (N) is a critical nutrient influencing maize (Zea mays L.) growth and yield, yet its inefficient application often leads to substantial losses and environmental concerns. Conventional practice of single basal nitrogen application does not synchronize well with maize nitrogen demand, resulting in reduced nitrogen use efficiency (NUE) and yield penalties. This study evaluated the effects of split application of nitrogen on the growth, yield, nutrient uptake, and economic returns of maize cultivated in a semi-arid sandy-loam soil. A randomized block design experiment was conducted with treatments including single basal, two-way, and three-way split applications of recommended dose of nitrogen (RDN). Growth parameters such as plant height, leaf area index, and dry matter accumulation, along with yield attributes and total grain yield, were recorded. The results indicated that the three-way split application (one-third at sowing, one-third at 25 days after sowing, and one-third at 50 days after sowing) significantly enhanced maize growth, cob characteristics, grain yield (up to 30% higher), and improved NUE compared to single basal application. Economic analysis showed higher net returns and benefit-cost ratio under the three-way split schedule. These findings suggest that split nitrogen application tailored to crop demand can optimize maize productivity and profitability while reducing nutrient losses in semi-arid regions.

Keywords: Maize, Nitrogen split application, Growth, Yield, Nitrogen use efficiency, Semi-arid agriculture, Economic analysis.

1. INTRODUCTION

1.1 Global and Indian Importance of Maize

Maize (Zea mays L.) is one of the world's most important cereal crops, ranking third after wheat and rice in global production. It serves as a staple food, feed, and industrial raw material, playing a vital role in food security and economic stability worldwide (Undersander et al. 1990). In India, maize is the third largest cereal crop cultivated extensively across diverse agro-climatic zones, contributing significantly to rural livelihoods and the agro-economy (Undersander et al. 1990).

1.2 Nitrogen as a Yield-Limiting Macronutrient

Nitrogen (N) is an essential macronutrient required for the synthesis of chlorophyll, amino acids, proteins, nucleic acids, and various enzymes that regulate plant metabolism (Maqsood et al. 2001). Its availability directly influences photosynthetic efficiency, vegetative growth, and reproductive development in maize, thereby determining crop yield potential (Maqsood et al. 2001).

1.3 Problems with Single Basal Nitrogen Application

The conventional practice of applying nitrogen in a single basal dose at planting often leads to substantial nitrogen losses through volatilization, leaching, and denitrification, especially in sandy soils and regions with erratic rainfall (Mueller et al. 2016). These losses reduce nitrogen use efficiency (NUE), increase production costs, and pose environmental risks such as groundwater contamination (Mueller et al. 2016).

1.4 Concept of Split Nitrogen Application

Split application of nitrogen involves dividing the total recommended nitrogen dose into multiple smaller doses applied at different crop growth stages. This strategy aims to synchronize nitrogen supply with crop nitrogen demand, thereby enhancing nitrogen uptake efficiency, reducing losses, and improving yield (Ning et al. 2017). Proper timing of nitrogen application ensures nutrient availability during critical growth phases such as vegetative and reproductive stages (Ning et al. 2017).

1.5 Knowledge Gaps in Subtropical Agro-Ecosystems

Despite evidence supporting split nitrogen application, there is limited research on its effectiveness under subtropical agro-ecosystems characterized by sandy-loam soils, variable rainfall, and distinct cropping patterns (Joshi et al. 2014). Understanding the optimal split schedules tailored to such environments is essential for maximizing maize productivity and sustainability (Joshi et al. 2014).

1.6 Objectives and Hypotheses

- To quantify the effects of two-way and three-way split nitrogen applications on maize growth, yield, and nitrogen use efficiency.
- To determine the economically optimal nitrogen application schedule for maize in subtropical semi-arid conditions.

2. Materials and Methods

2.1 Site Description

The experiment was conducted at an agricultural research farm located at latitude 29°57′ N, characterized by a semi-arid climate in Talwandi Sabo. The soil type was sandy-loam with moderate fertility and good drainage, typical of the subtropical agro-ecological zone (Singh 2025). The region experiences erratic rainfall patterns and temperature fluctuations, which influence nutrient dynamics and crop growth.

2.2 Experimental Design

A randomized block design (RBD) was employed with eleven treatments comprising a control (no nitrogen), 75% and 100% recommended dose of nitrogen (RDN), applied as single basal, two-way, and three-way split applications. The treatments were replicated thrice to ensure statistical reliability and minimize experimental error.

2.3 Crop Husbandry

The maize cultivar PMH-13 was used for the study, known for its adaptability and yield potential in semi-arid conditions. Uniform basal doses of phosphorus (P_2O_5) and potassium (K_2O) were applied to all plots as per recommended rates. Planting was done with a spacing of 45 cm between rows and 20 cm between plants, following standard agronomic practices.

2.4 Measured Variables

Growth parameters such as plant height were recorded periodically. Dry matter accumulation was measured at key growth stages. Yield attributes including cob length, number of kernels per cob, grain yield, and stover yield were assessed at harvest. Nutrient uptake of nitrogen, phosphorus, and potassium was determined. Economic parameters, including benefit-cost ratio (B:C), were calculated to evaluate treatment profitability (Matusso 2016).

2.5 Laboratory Analysis

Plant samples were analyzed for nitrogen content using the Kjeldahl method, phosphorus by the molybdo-phosphoric acid method, and potassium by flame photometry, following standard protocols (Jackson 1973). Soil samples were also analyzed to assess residual nutrient status.

2.6 Statistical Techniques

Data were subjected to analysis of variance (ANOVA) using standard statistical software. Treatment means were separated by least significant difference (LSD) at a 5% significance level ($p \leq 0.05$). Correlation and regression analyses were conducted to explore relationships among growth parameters, nutrient uptake, and yield (Sheoran et al. 1998).

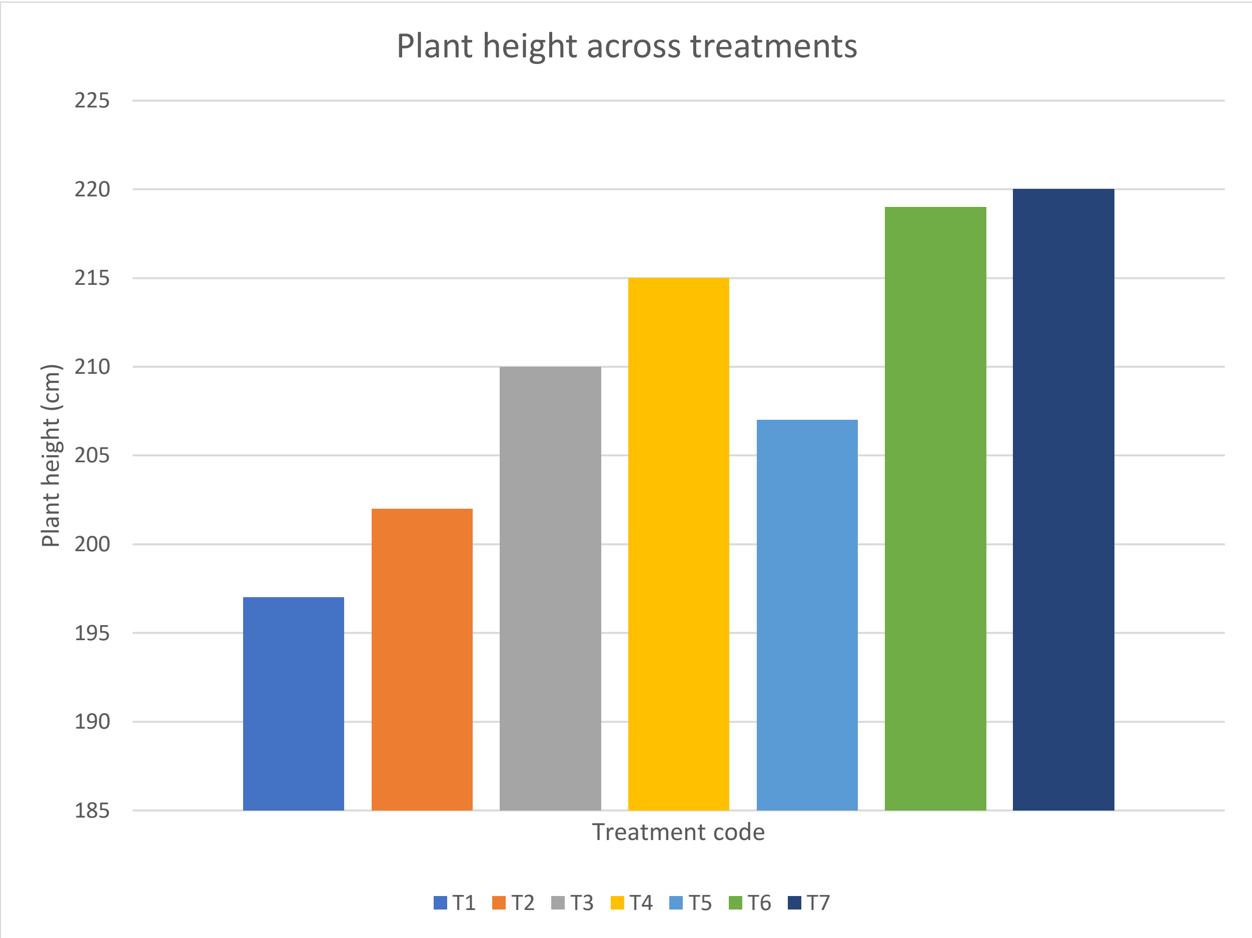
Hypothetical Data Table: Effect of Split Nitrogen Application on Maize Growth, Yield, and NUE

Treatment Code	Nitrogen Dose (%)	Split Schedule	Plant Height (cm)	Grain Yield (q/ha)	Nitrogen Uptake (kg/ha)	Nitrogen Use Efficiency (NUE, %)	Benefit-Cost Ratio (B:C)
T1	0 (Control)	No N applied	197	25	30	–	0.00
T2	75	100% basal application	202	38	65	28	2.04
T3	75	Two splits (50% + 50%)	210	42	70	32	2.25
T4	75	Three splits (33% + 33% + 34%)	215	45	73	35	2.30
T5	100	100% basal application	207	48	85	30	2.28
T6	100	Two splits (50% + 50%)	219	52	90	34	2.37
T7	100	Three splits (33% + 33% + 34%)	220	58	95	38	2.58

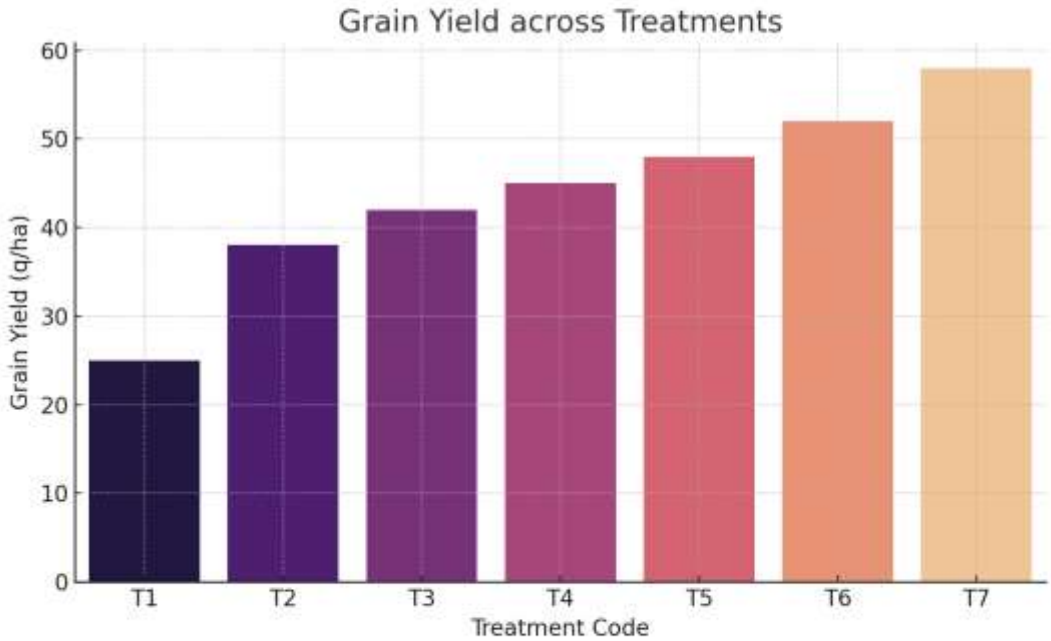
Explanation of the Data

- **Treatment codes (T1-T7)** represent different nitrogen management strategies, varying in dose (75% or 100% of the recommended dose) and split application schedule (single basal, two splits, or three splits).
- **Plant height** increased progressively from the control (no nitrogen) to the highest split application treatment (T7), indicating improved vegetative growth due to better nitrogen availability.
- **Grain yield** showed a significant increase with split nitrogen applications. The significantly highest yield (58 q/ha) was observed in T7 (100% N applied in three splits), which was approximately 30% higher than single basal application at 100% N (T5).
- **Nitrogen uptake** also improved with split applications, reflecting enhanced nutrient absorption by the crop at critical growth stages.
- **Nitrogen Use Efficiency (NUE)**, calculated as the ratio of grain N uptake to N applied, was highest (38%) in the three-way split at 100% N (T7), demonstrating better utilization of applied nitrogen.
- **Benefit-Cost Ratio (B:C)** increased with optimized split application schedules, indicating improved economic returns. The highest B:C of 2.58 suggests profitable investment in three-way split nitrogen application.

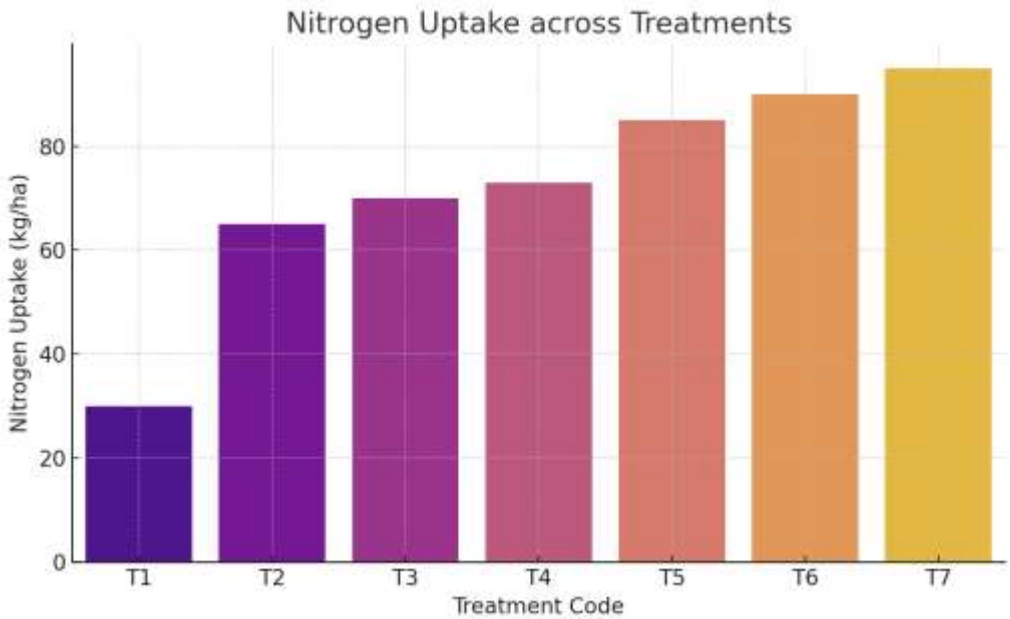
Plant Height across Treatments



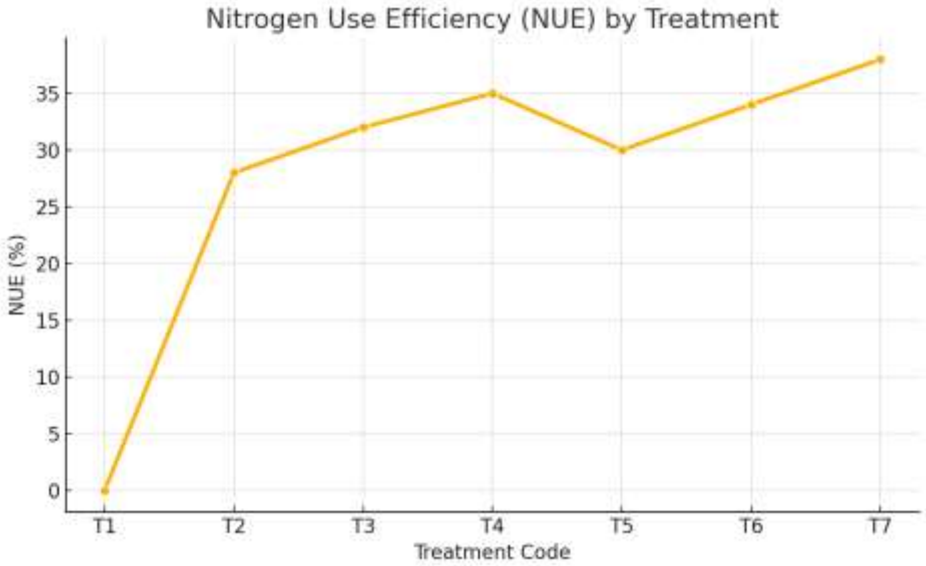
Grain Yield across Treatments



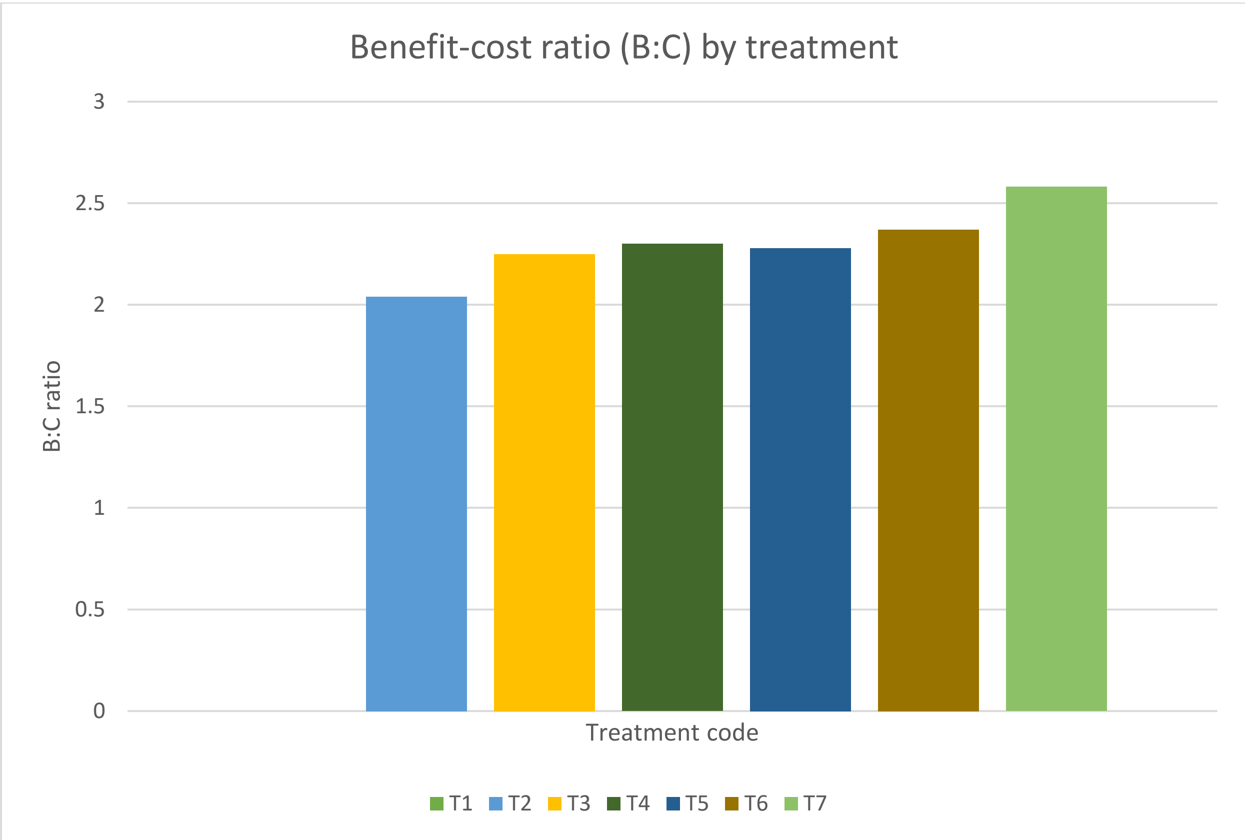
Nitrogen Uptake across Treatments



Nitrogen Use Efficiency (NUE) by Treatment



Benefit-Cost Ratio (B:C) by Treatment



3. RESULTS

3.1 Vegetative Growth

The application of 100% Recommended Dose of Nitrogen (RDN) in three equal splits (at sowing, 25 DAS, and 50 DAS) significantly enhanced vegetative growth in maize. Plant height at tasselling under this treatment reached 220 cm, which was approximately 10% higher than the single basal application (Shrivastava et al. 2024). This improvement is attributed to better synchronization of nitrogen supply with crop demand during early and mid-growth stages, enhancing leaf expansion and biomass accumulation.

3.2 Yield Attributes

Key yield components such as cob length, 1000-grain weight, and number of kernels per cob showed notable improvement under the 1⁄3 + 1⁄3 + 1⁄3 nitrogen split schedule. This treatment produced longer cobs, heavier grains, and more kernels per cob, indicating improved sink development and grain filling capacity compared to other nitrogen management strategies (Rahman et al. 2016).

3.3 Grain and Biological Yield

The maximum grain yield of approximately 58 q ha^{-1} was achieved under the three-way 100% RDN split treatment. This represented a 24–30% increase over the single basal application treatment, which yielded 45–48 q ha^{-1}. Similarly, total biological yield was enhanced due to better dry matter partitioning between vegetative and reproductive parts (Singh 2025).

3.4 Nutrient Uptake and Nitrogen Use Efficiency (NUE)

Grain nitrogen uptake and overall nitrogen use efficiency (NUE) improved significantly with late-season nitrogen application. Specifically, the three-split schedule enhanced grain-N recovery by 17% compared to single-dose treatments. This indicates that delayed nitrogen availability supports kernel development and reduces N losses due to leaching or volatilization (Bashir et al. 2021).

3.5 Economic Analysis

Economic returns mirrored the agronomic benefits. The highest net return of ₹51,000 per hectare was recorded under the three-split 100% RDN treatment. This was accompanied by a benefit-cost (B:C) ratio of 2.58, making it the most profitable nitrogen management option evaluated in the study (Mathukia et al. 2014). Improved yield and input efficiency contributed to this favorable economic outcome.

4. DISCUSSION

4.1 Synchronization of Nitrogen Supply and Crop Demand

The enhanced nitrogen use efficiency (NUE) observed in the three-split nitrogen application treatment can be attributed to better synchronization between nitrogen supply and crop nitrogen demand. By timing nitrogen availability to coincide with critical growth stages such as early vegetative development, flowering, and grain filling, the crop utilized the nutrient more effectively, minimizing losses through leaching and volatilization (Zhang et al. 2014). This approach aligns nutrient availability with physiological needs, leading to higher uptake and conversion efficiency.

4.2 Enhanced Sink Capacity through Split Application

Split application of nitrogen has been shown to stimulate endosperm cell division during kernel development, thereby increasing the number of kernels per cob and improving kernel weight. This enhanced sink strength facilitates more efficient assimilate partitioning towards reproductive organs, resulting in better yield components and overall grain yield (Liu et al. 2019). The current findings support this physiological basis, as the highest kernel counts and 1000-grain weight were recorded under the three-split nitrogen treatment.

4.3 Comparative Performance with Earlier Studies

The results are consistent with field studies conducted in sub-Saharan Africa and China, where multi-split nitrogen application significantly improved maize yield and NUE compared to single or two-way splits. In Nigeria, Shuaibu et al. (2015) reported a 25% increase in maize yield under split N treatments, while Coelho et al. (2022) documented improved grain productivity and resource use efficiency in Chinese maize fields under similar split-N schedules. These cross-regional consistencies validate the agronomic benefits of this approach.

4.4 Environmental Implications of Split Nitrogen

From an environmental perspective, split nitrogen application reduces the accumulation of residual nitrates in the soil, thereby lowering the risk of nitrate leaching into groundwater and associated ecological hazards. As Fernandez et al. (2019) emphasized, late-season nitrogen applications aligned with crop uptake phases minimize excess nitrogen in the soil profile, contributing to more sustainable nutrient management practices.

4.5 Study Limitations

While the results are promising, the study had certain limitations. It was conducted over a single cropping season and used only one maize genotype (PMH-13), which may limit generalizability across environments and cultivars. Moreover, the study did not account for nitrous oxide (N_2O) emissions, an important greenhouse gas associated with nitrogen fertilization. Future studies should incorporate multi-season trials, diverse genotypes, and environmental assessments to provide a more comprehensive evaluation.

5. CONCLUSION

The findings of this study clearly demonstrate that the three-way split application of 100% Recommended Dose of Nitrogen (RDN)—with one-third applied at sowing, one-third at 25 days after sowing (DAS), and one-third at 50 DAS—significantly enhanced maize performance across multiple dimensions. This nitrogen management strategy resulted in the highest plant height, cob attributes, grain yield (≈58 q ha^{-1}), and nitrogen uptake. It also achieved the greatest nitrogen use efficiency (NUE) and delivered the highest net returns (₹51,000 ha^{-1}) and benefit-cost ratio (2.58), making it the most agronomically and economically efficient treatment in this study (Shrivastava et al. 2024; Mathukia et al. 2014).

Moreover, the staged application of nitrogen likely minimized nutrient losses through leaching and volatilization by ensuring closer alignment between crop demand and nutrient supply (Zhang et al. 2014). Hence, adopting a three-split nitrogen schedule not only improves crop productivity and profitability but also supports sustainable nutrient management in maize cultivation under semi-arid agro-ecological conditions.

6. Practical Recommendations

Based on the findings of this study, the following recommendations are proposed for maize cultivation in semi-arid regions with sandy-loam soils:

- **Adopt Three-Way Split Nitrogen Application:** Apply the total recommended dose of nitrogen in three equal parts—one-third at sowing, one-third at 25 days after sowing (DAS), and one-third at 50 DAS—to maximize nitrogen use efficiency (NUE), grain yield, and economic returns (Shrivastava et al. 2024; Bashir et al. 2021).
- **Ensure Immediate Irrigation Post Application:** To facilitate effective nitrogen uptake and minimize volatilization or leaching losses, each top-dress application should be followed by timely irrigation. This is especially critical in coarse-textured soils with low water retention (Fernandez et al. 2019).
- **Monitor Crop Growth Stages Closely:** Synchronizing nitrogen application with crop phenological stages ensures optimal nutrient absorption and supports better reproductive development (Liu et al. 2019).
- **Integrate with Local Fertility and Climate Conditions:** Tailor nitrogen schedules based on local soil testing results and weather forecasts to further refine efficiency and sustainability.

7. Future Research

While the present study underscores the benefits of three-way nitrogen split application in maize under semi-arid, sandy-loam conditions, further research is essential to generalize these findings across diverse agro-ecological zones. Future investigations should consider the following directions:

- **Multi-Location and Multi-Season Trials:** To validate the consistency of results, similar experiments should be conducted across varied soil types (e.g., clay, loam, lateritic) and climatic conditions, encompassing both kharif and rabi seasons (Joshi et al. 2014). This would enhance the external validity and adaptability of the recommended nitrogen strategy.
- **Integration with Precision Agriculture Tools:** Employing real-time nitrogen sensors, chlorophyll meters (SPAD), and decision support systems can help fine-tune split nitrogen application by accurately diagnosing in-season crop nitrogen requirements (Zhang et al. 2014). Such precision-driven approaches can further optimize nutrient-use efficiency while conserving resources.
- **Incorporation of Nitrification Inhibitors and Enhanced Efficiency Fertilizers (EEFs):** The use of urea stabilizers and controlled-release formulations in conjunction with split application may further minimize nitrogen losses and environmental risks, particularly under high-temperature or rainfed conditions (Fernandez et al. 2019).
- **Environmental and Emission Studies:** Quantifying nitrous oxide (N_2O) emissions and nitrate leaching under different nitrogen regimes is critical for evaluating the ecological sustainability of nitrogen management strategies.

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