JOURNAL OF FOOD AND BIOTECHNOLOGY

Original Research Article | ISSN 3041- 6299 | Open Access

Effect of Zinc and Boron Application on Growth, Yield, and Profitability of Maize (*Zea mays* L.) in Semi-Arid region of Bundelkhand India

Sanjana Yadav*, Avnish Kumar Tripathi, Ashesh Narayan and Satya Dev Shakya

Department of Agronomy, Nehru Mahavidyalaya, Lalitpur, Uttar Pradesh 284403, India

Corresponding author: **Sanjana Yadav** | E-mail: **yadavsanjana219@gmail.com**

Citation: Sanjana Yadav, Avnish Kumar Tripathi, Ashesh Narayan and Satya Dev Shakya (2026). Effect of Zinc and Boron Application on Growth, Yield, and Profitability of Maize (*Zea mays* L.) in Semi-Arid region of Bundelkhand India. *Journal of Food and Biotechnology.* **88 to 93. DOI: https://doi.org/10.51470/FAB.2026.7.1.88**

25 January 2026: Received | 22 February 2026: Revised | 18 March 2026: Accepted | 14 April 2026: Available Online

Abstract

Balanced micronutrient management is essential for improving maize productivity, particularly in semi-arid regions where soil nutrient deficiencies are widespread. The present study was conducted to evaluate the effect of zinc (Zn) and boron (B) on the growth, yield, and economic performance of maize (Zea mays L.) in the Bundelkhand region of Uttar Pradesh, India. A field experiment was carried out during the Kharif season of 2025 at the Agricultural Research Farm, Nehru Mahavidyalaya, Lalitpur, using a randomized block design (RBD) with nine treatments and three replications. The treatments comprised different levels and combinations of zinc and boron applied through soil and/or foliar methods. Observations were recorded on growth parameters, yield attributes, grain and stover yield, and economic returns. The results indicated that micronutrient application significantly improved crop performance over the control. The combined application of zinc and boron (T_9) proved most effective, recording the highest values of growth parameters, including number of leaves and dry matter accumulation. Yield attributes such as number of cobs per plant, grains per cob, cob length, and test weight were also significantly enhanced under this treatment. Consequently, the highest grain yield (52.1 q ha^{-1}), stover yield (93.5 q ha^{-1}), and harvest index (35.8%) were recorded in T_9. Economic analysis revealed that the same treatment resulted in maximum gross and net returns with a benefit–cost ratio of 2.16, indicating its economic superiority. Thus, the combined application of zinc and boron is an effective and economically viable strategy for enhancing maize productivity under semi-arid conditions.

Keywords: *Zinc; Boron; Micronutrient management; Maize (Zea mays L.); Growth parameters; Yield attributes.*

1. Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops globally and plays a crucial role in ensuring food, feed, and industrial security. It is often referred to as the "queen of cereals" due to its high genetic yield potential and adaptability to diverse agro-climatic conditions. Globally, maize ranks among the top three cereal crops, and in India, it occupies the third position after rice and wheat, contributing significantly to the agricultural economy and allied industries such as poultry, starch, and biofuel sectors [1-2]. Its versatility as a food, fodder, and industrial crop makes it indispensable in sustaining both rural livelihoods and modern agricultural systems. However, despite its importance, maize productivity in many regions remains below its potential due to multiple constraints, among which nutrient imbalance is a major limiting factor. One of the critical challenges faced by modern agriculture is the declining soil fertility and nutrient imbalance, largely driven by intensive cropping and imbalanced fertilizer use. It is estimated that Indian soils experience an annual nutrient depletion of approximately 30 million tonnes, whereas only about 20 million tonnes are replenished through fertilization, resulting in a net deficit [2]. This imbalance has led to a significant decline in fertilizer response ratios over time, thereby affecting crop productivity and sustainability. Conventional fertilizer practices, primarily focused on macronutrients (N, P, and K), often neglect micronutrients, leading to hidden hunger in crops and reduced nutrient use efficiency. Recent studies emphasize that balanced fertilization, including micronutrients, is essential for sustaining crop productivity under changing climatic conditions [3]. Micronutrients, though required in small quantities, play a vital role in plant growth and development by regulating key physiological and biochemical processes. Among these, zinc (Zn) and boron (B) are particularly important for maize production. Zinc is involved in enzyme activation, protein synthesis, chlorophyll formation, and auxin metabolism, thereby influencing plant growth and development. It also plays a crucial role in enhancing photosynthetic efficiency and stress tolerance. On the other hand, boron is essential for cell wall formation, membrane stability, sugar transport, and reproductive development, particularly pollen viability and fertilization processes [4]. The importance of micronutrients is further highlighted by the fact that they act as catalysts in metabolic pathways and significantly influence nutrient uptake and utilization efficiency [5]. Despite their importance, micronutrient deficiencies are increasingly becoming widespread in agricultural soils.

Zinc deficiency, in particular, is a global problem affecting nearly 50% of cereal-growing soils, leading to reduced crop yields and nutritional quality . In India, zinc deficiency is prevalent in a large proportion of cultivated soils, especially in calcareous and alkaline regions. Similarly, boron deficiency is commonly observed in light-textured and nutrient-depleted soils, resulting in poor reproductive development, reduced grain setting, and ultimately lower yields. Studies have shown that boron deficiency can lead to impaired pollen viability, reduced fertilization, and significant yield losses in maize . These deficiencies not only limit crop productivity but also affect the nutritional quality of produce, contributing to micronutrient malnutrition in humans. Recent research has highlighted the synergistic effects of combined micronutrient application, particularly zinc and boron, in improving crop growth and yield. The combined application of Zn and B has been shown to enhance physiological efficiency, increase biomass production, and improve yield attributes such as cob formation, grain number, and test weight. A study by [6] reported that integrated application of zinc and boron significantly improved maize growth, yield, and grain quality, demonstrating their complementary roles in crop nutrition . Similarly, [7] observed that combined micronutrient application enhanced plant height, grain weight, and overall productivity, indicating strong synergistic interactions between micronutrients . These findings suggest that integrated micronutrient management is a promising approach for enhancing maize productivity and ensuring sustainable agriculture.

The Bundelkhand region of Uttar Pradesh represents a typical semi-arid agro-ecosystem characterized by erratic rainfall, degraded soils, and low nutrient availability. Agriculture in this region is largely rainfed and highly vulnerable to environmental stresses, making efficient nutrient management a critical requirement for improving crop productivity. Soils in Bundelkhand are often deficient in micronutrients due to continuous cropping, low organic matter content, and limited use of balanced fertilizers. Despite the importance of micronutrients, there is a lack of region-specific studies focusing on their integrated application in maize production systems. Most of the existing research has focused on individual nutrient application, with limited emphasis on the combined effects of zinc and boron under semi-arid conditions, with increasing concerns about food and nutritional security, there is a growing need to enhance not only crop yield but also the nutritional quality of produce through biofortification strategies. Micronutrient management, particularly zinc application, plays a crucial role in improving grain nutritional quality, thereby addressing hidden hunger and micronutrient deficiencies in human populations . However, the effectiveness of such strategies depends on optimizing nutrient combinations and application methods under specific agro-ecological conditions. Therefore, the present study was conducted to evaluate the effect of zinc and boron on growth, yield, and economics of maize under Bundelkhand conditions.

2. Materials and Methods

2.1 Study Area

The field experiment was conducted during the Kharif season of 2025 at the Agricultural Research Farm, Nehru Mahavidyalaya, Lalitpur, Uttar Pradesh, India, located in the Bundelkhand region. The experimental site lies between 25.45°–25.47° N latitude and 78.60°–78.62° E longitude, at an elevation of approximately 222–285 m above mean sea level. The region is characterized by a semi-arid climate, with hot summers, mild winters, and erratic monsoon rainfall (Fig. 1)l. The soil of the experimental field was sandy loam in texture, fairly uniform in fertility status, and suitable for maize cultivation.

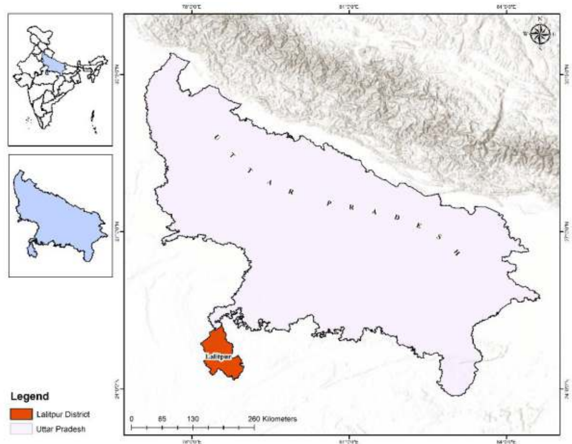

Fig 1: Location map of the experimental site at Nehru Mahavidyalaya, Lalitpur, Jhansi district, Uttar Pradesh, India

2.2 Experimental Design

The experiment was laid out in a Randomized Block Design (RBD) with nine treatments and three replications. The treatments were randomly allocated within each replication to minimize experimental error and ensure statistical reliability.

2.3 Treatments

The details of nutrient management treatments involving zinc (Zn) and boron (B) are presented in Table 1.

Table 1: Treatment details of zinc and boron application in maize

Symbols	Treatments
T_1	Control (no micronutrient application)
T_2	100% RDF+0.5% Zn (foliar)
T_3	100% RDF + 0.2% B (foliar)
T_4	125% RDF + 0.5% Zn (foliar)
T_5	125% RDF + 0.2% B (foliar)
T_6	100% RDF + (0.5% Zn+0.2%B) (foliar)
T_7	125% RDF + (0.5% Zn+0.2% B) (foliar)
T_8	100% RDF + (0.5% Zn + 0.4% B) (foliar)
T_9	125% RDF + (0.5% Zn+0.4% B) (foliar)

2.4 Crop Details

Maize (*Zea mays* L.) was grown as the test crop during the Kharif season of 2025 following recommended agronomic practices. Standard procedures for land preparation, sowing, fertilization, irrigation, and plant protection were uniformly adopted across all treatments to ensure consistency in crop management.

2.5 Observations Recorded

Observations were recorded at different growth stages and categorized as follows:

1. Growth parameters: Plant height (cm), number of leaves per plant, leaf area index (LAI), and dry matter accumulation (g $plant^{-1}$).
2. Growth indices: Crop growth rate (CGR) and absolute growth rate (AGR).
3. Yield attributes: Number of cobs per plant, number of grains per cob, cob length, and test weight.
4. Yield: Grain yield (q ha^{-1}), stover yield (q ha^{-1}), and harvest index (%).
5. Economic analysis: Cost of cultivation, gross returns, net returns, and benefit–cost (B:C) ratio.

2.6 Statistical Analysis

The experimental data were analyzed statistically using analysis of variance (ANOVA) appropriate for the Randomized Block Design, following standard procedures (Gomez and Gomez, 1984). The significance of treatment effects was tested at the 5% level of probability ($p = 0.05$), and the critical difference (CD) was calculated for comparison of treatment means.

3. Results

3.1 Growth Parameters

Growth parameters of maize were significantly influenced by different nutrient management treatments involving zinc (Zn) and boron (B). The data indicated clear variation among treatments with respect to plant height, number of leaves, leaf area index (LAI), and dry matter accumulation. Plant height increased progressively with crop growth under all treatments; however, the magnitude of increase varied significantly depending on nutrient application. The combined application of zinc and boron (T_9) consistently recorded the maximum plant height at all growth stages, which was significantly superior to the control and other individual treatments. The enhanced plant height under T_9 can be attributed to improved metabolic activity, better nutrient uptake, and increased cell division and elongation due to micronutrient availability. Similarly, the number of leaves per plant was significantly influenced by nutrient treatments. The highest leaf count was recorded under T_9, reaching 17.3 leaves per plant at harvest, which was markedly higher than all other treatments. Increased leaf production under combined micronutrient application suggests enhanced photosynthetic capacity and better vegetative growth.

Leaf area index (LAI), which is a critical indicator of canopy development and light interception, also followed a similar trend, with T_9 recording the highest values. This indicates improved canopy structure and efficient utilization of solar radiation. Dry matter accumulation showed a significant increase with micronutrient application. The highest dry matter production was recorded under T_9 (185.6 g $plant^{-1}$ at harvest), followed by treatments T_7 and T_8, indicating the beneficial effect of combined Zn and B application on biomass production. The improvement in dry matter accumulation reflects enhanced physiological efficiency and better translocation of assimilates (Fig. 2 and 3). In contrast, the control treatment recorded the lowest values for all growth parameters, highlighting the importance of micronutrient supplementation in maize cultivation.

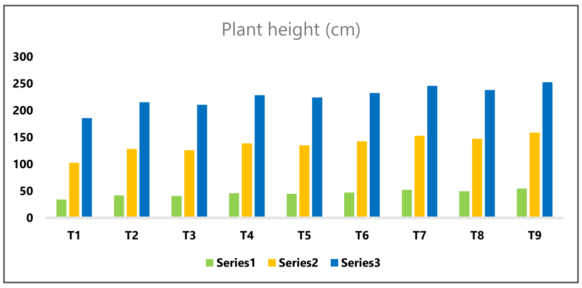

Fig. 2: Plant height of maize

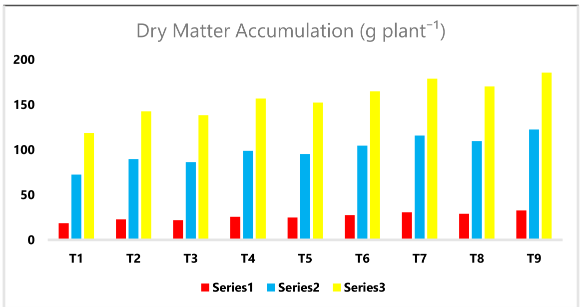

Fig. 3: Dry matter accumulation of maize

3.2 Growth Indices

Growth indices such as crop growth rate (CGR) and absolute growth rate (AGR) are important indicators of crop physiological performance and biomass accumulation over time. These indices were significantly affected by different nutrient management practices. The results revealed that both CGR and AGR increased progressively with crop age, reaching peak values during the active vegetative growth phase. Among the treatments, T_9 recorded the highest CGR and AGR values, indicating superior growth dynamics and efficient biomass accumulation. The higher CGR under T_9 suggests enhanced photosynthetic activity and improved conversion of assimilates into plant biomass. Similarly, increased AGR reflects better individual plant growth performance, which can be attributed to the synergistic effect of zinc and boron on metabolic processes. Treatments involving individual application of zinc or boron showed moderate improvement in growth indices compared to the control, but were significantly inferior to combined applications. This indicates that single micronutrient application may not be sufficient to achieve optimal physiological efficiency. The control treatment recorded the lowest CGR and AGR values, indicating restricted growth due to nutrient deficiency, the results demonstrate that integrated micronutrient management enhances physiological efficiency and promotes vigorous crop growth (Fig. 4 and 5).

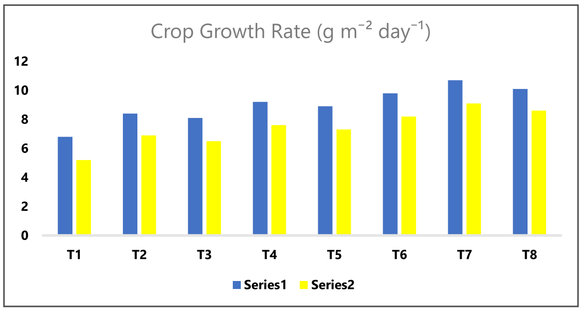

Fig. 4: Crop Growth Rate (CGR) (g m^{-2} day^{-1}) of maize

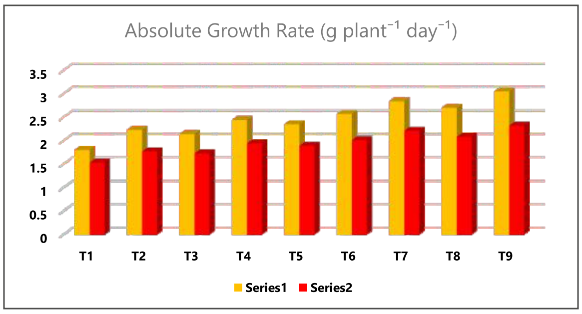

Fig. 5: Absolute Growth Rate (g plant^{-1} day^{-1}) of maize

3.3 Yield Attributes and Productivity

Yield attributes and productivity of maize were significantly influenced by the application of zinc and boron. The superiority of combined micronutrient application was clearly reflected in improved yield components. The treatment T_9 recorded the highest number of cobs per plant (1.21), which was significantly higher than the control and other treatments. Similarly, the number of grains per cob was maximum under T_9 (489 grains per cob), indicating improved reproductive efficiency. Cob length and test weight were also significantly enhanced under T_9, with the highest test weight recorded at 286.3 g, reflecting better grain filling and development. These improvements in yield attributes can be attributed to enhanced nutrient availability during critical reproductive stages, resulting in better pollination, fertilization, and assimilate translocation. Grain yield was significantly affected by nutrient treatments, with T_9 recording the highest grain yield of 52.1 q ha^{-1}, followed by T_7 and T_8. The yield under T_9 was substantially higher than the control, demonstrating the effectiveness of combined micronutrient application. Stover yield also followed a similar trend, with T_9 recording the highest stover yield (93.5 q ha^{-1}), indicating improved vegetative growth and biomass production. The harvest index was also highest under T_9 (35.8%), suggesting efficient partitioning of assimilates towards economic yield. The control treatment recorded the lowest yield and yield attributes due to nutrient deficiency, which limited both vegetative and reproductive growth. The results clearly indicate that combined application of zinc and boron significantly enhances yield performance in maize (Fig. 6 and 7).

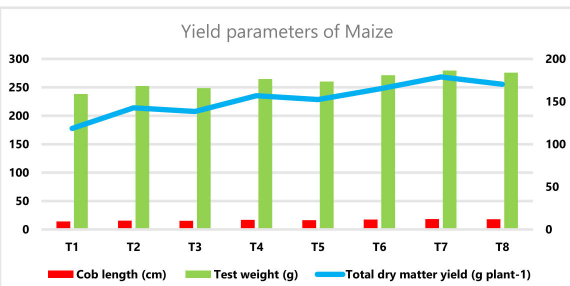

Fig. 6: Yield parameters of Maize

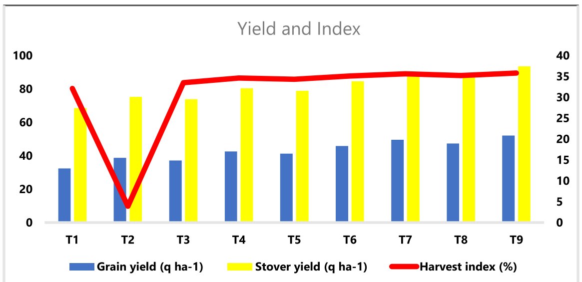

Fig. 7: Yield and Harvest Index of Maize

3.4 Economic Analysis

Economic analysis is a critical component for evaluating the practical feasibility of nutrient management practices. The results revealed significant variation in economic returns among treatments. The treatment T_9 recorded the highest gross returns and net returns, with a net return of ₹55,900 ha^{-1}, indicating its economic superiority. This treatment also achieved the highest benefit–cost (B:C) ratio of 2.16, making it the most profitable option among all treatments. The higher profitability of T_9 can be attributed to its ability to produce higher yields without a proportionate increase in cost of cultivation. The combined application of zinc and boron improved both productivity and economic efficiency, making it a viable option for farmers. Treatments involving individual micronutrient application showed moderate economic returns, whereas the control treatment recorded the lowest profitability due to poor yield performance. These findings highlight that balanced micronutrient management not only improves crop productivity but also enhances farm income, which is essential for sustainable agricultural practices (Fig. 8).

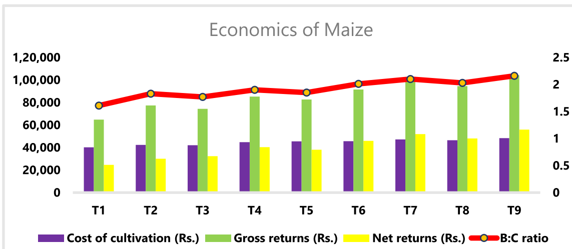

Fig. 8: Economics of Maize cultivation

4. Discussion

The results of the present study clearly demonstrate that the combined application of zinc (Zn) and boron (B) (T_9) significantly enhanced growth, yield attributes, productivity, and economic returns of maize under Bundelkhand conditions. The superiority of this treatment can be explained through the complementary physiological roles of these micronutrients and their synergistic interaction in plant metabolic processes. The improved growth performance observed under T_9, particularly in terms of plant height, leaf number, and dry matter accumulation, can be attributed to the critical role of zinc in plant metabolism.

Zinc is known to function as an activator of several enzymes involved in carbohydrate metabolism, protein synthesis, and nucleic acid formation. It also plays a key role in the synthesis of auxins, which regulate cell division and elongation, thereby contributing to increased plant height and biomass production. Recent studies have confirmed that zinc significantly enhances enzymatic activity and hormonal balance, leading to improved vegetative growth and physiological efficiency [8-9]. On the other hand, boron plays a vital role in reproductive development and assimilate translocation, particularly in processes such as pollen germination, fertilization, and seed formation. It is essential for maintaining cell wall integrity and facilitating the movement of sugars from source to sink. Adequate boron availability ensures proper reproductive development, resulting in improved cob formation and grain setting. Recent findings indicate that boron is crucial for pollen viability and carbohydrate transport, which directly influences grain yield [10]. The combined application of Zn and B in T_9 resulted in a synergistic effect, which was evident from the significant improvements in both growth and yield parameters. This synergy can be explained by the complementary roles of these nutrients: while zinc enhances vegetative growth and metabolic activity, boron ensures efficient reproductive development and assimilate partitioning. Such interactions lead to improved overall plant performance compared to individual nutrient application. Similar findings have been reported by [11], who observed that combined application of zinc and boron significantly improved growth, yield, and grain quality of maize. The increase in dry matter accumulation under T_9 played a crucial role in enhancing yield attributes and final productivity. Higher biomass production indicates improved photosynthetic efficiency and resource utilization, which ultimately leads to increased assimilate availability for grain development. The relationship between dry matter accumulation and yield observed in the present study supports the concept that greater biomass production results in higher yield through efficient assimilate partitioning. This is further supported by studies showing that micronutrient application enhances physiological processes and biomass production, thereby improving yield outcomes. The significant improvement in yield attributes such as number of cobs per plant, grains per cob, and test weight under T_9 can be attributed to better reproductive efficiency and nutrient availability during critical growth stages. Zinc contributes to enhanced enzyme activity and photosynthesis, while boron facilitates pollen germination and fertilization, leading to improved grain setting. This combination ensures that the assimilates produced during vegetative growth are effectively utilized for reproductive development. The findings of the present study are in close agreement with earlier reports. [12] reported that combined application of zinc and boron significantly increased growth parameters, yield attributes, and grain yield in maize due to improved nutrient uptake and metabolic activity. Similarly, [13] observed that zinc application enhanced grain yield and biomass production, while boron contributed to improved reproductive performance and grain formation. Recent studies also highlight that integrated micronutrient management significantly improves crop productivity by enhancing nutrient use efficiency and physiological processes [14-18].

Furthermore, the enhanced economic returns under T_9 can be directly linked to improved yield performance and efficient utilization of applied nutrients. The higher benefit–cost ratio indicates that the combined application of zinc and boron is not only agronomically effective but also economically viable for farmers. This is particularly important in semi-arid regions like Bundelkhand, where resource optimization is critical for sustainable agriculture. Thus, the results confirm that the combined application of zinc and boron improves maize productivity through enhanced growth, better assimilate partitioning, and improved reproductive efficiency. The synergistic interaction between these micronutrients plays a key role in optimizing crop performance under nutrient-deficient conditions.

5. Conclusion

The present study demonstrates that balanced micronutrient management significantly enhances maize productivity under semi-arid conditions. The combined application of zinc and boron (T_9) proved to be the most effective treatment, resulting in superior growth, yield attributes, and grain yield. This improvement was associated with increased dry matter accumulation and better assimilate partitioning, leading to higher economic returns. The treatment also recorded the highest benefit–cost ratio, confirming its economic viability. Therefore, the integrated application of zinc and boron can be recommended as an efficient and sustainable nutrient management strategy for maize cultivation in the Bundelkhand region.

6. Recommendations

Based on the findings of the present study, the combined application of zinc and boron is recommended for improving maize productivity under Bundelkhand conditions. Emphasis should be given to the application of these micronutrients, particularly during critical growth stages such as flowering, to enhance reproductive efficiency and grain formation. This approach is not only agronomically effective but also economically feasible, making it highly suitable for small and marginal farmers seeking to maximize yield and profitability.

Acknowledgment

The authors sincerely acknowledge the support and facilities provided by the Department of Agronomy, Nehru Mahavidyalaya, Lalitpur (U.P.), for conducting this study. We are grateful to the supervisor and co-supervisor for their guidance and to all staff and field assistants for their help during the experiment.

References

1. Emam, S. M., & Osman, E. A. (2021). Integrated application of organic, bio and mineral fertilizers on nutrients uptake and productivity of Zea mays L. under semi-arid condition. *Journal of Plant Nutrition*, *44*(3), 309-321.
2. Alloway, B. J. (2004). Zinc in soils and crop nutrition. *International Zinc Association*.
3. Thakur, P., Kumar, P., Shukla, A. K., Butail, N. P., Sharma, M., Kumar, P., & Sharma, U. (2023). Quantitative, qualitative, and energy assessment of boron fertilization on maize production in North-West Himalayan Region. *International Journal of Plant Production*, *17*(1), 165-176.

4. Cioboată, D., Rusu, T., & Moraru, P. (2025). Influence of foliar fertilization with boron and zinc on maize yield. *Agronomy, 15*(2), 456.
5. Dawar, K., Ali, S., & Ahmad, N. (2025). Combined application of micronutrients enhances growth and yield of maize under climate stress conditions. *Scientific Reports, 15*, 18968.
6. Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research* (2nd ed.). John Wiley & Sons.
7. Gurmani, A. R., Bano, A., & Ullah, N. (2012). Role of micronutrients in plant growth and development: A review. *Soil & Environment, 31*(2), 95–102.
8. Cioboată, M. N., Păunescu, R. A., Florea, D. F., Roșculete, C. A., & Roșculete, E. (2025). Influence of Foliar Fertilization with Boron and Zinc for Maize Grain Crop in the Hilly Area of South-Western Romania. *Romanian Agricultural Research*, *42*, 577-586.
9. Ikramullah, I., Khan, M., & Khan, A. (2011). Growth and yield response of maize to different nutrient levels. *Sarhad Journal of Agriculture, 27*(4), 563–567.
10. Jarecki, W., Buczek, J., & Bobrecka-Jamro, D. (2025). Effect of zinc fertilization on maize yield and nutrient uptake. *Journal of Elementology, 30*(1), 145–156.
11. Kaya, C., & Higgs, D. (2002). Response of maize to zinc application under drought conditions. *Journal of Plant Nutrition, 25*(4), 799–808.
12. Khan, H. R., McDonald, G. K., & Rengel, Z. (2003). Zinc fertilization improves growth and water use efficiency of wheat. *Plant and Soil, 249*(2), 243–250.
13. Elshamly, A. M., & Abaza, A. S. (2024). Precise partial root-zone irrigation technique and potassium-zinc fertigation management improve maize physio-biochemical responses, yield, and water use in arid climate. *BMC plant biology*, *24*(1), 775.
14. Prusty, B. A. K., Rathore, S. S., & Singh, R. (2020). Micronutrient deficiencies in Indian soils and their management. *Indian Journal of Fertilisers, 16*(4), 44–58.
15. Pooniya, V., Shivay, Y. S., Pal, M., & Bansal, R. (2018). Relative performance of boron, sulphur and zinc coatings onto prilled urea for increasing productivity and nitrogen use efficiency in maize. *Experimental Agriculture*, *54*(4), 577-591.
16. Gholami, A., Maleki, A., Mirzaeiheydari, M., & Babaei, F. (2024). Effect of nitrogen fertilizer and zinc sulfate on growth, physiological, biochemical and nutrient use efficiency in fodder maize under irrigation regimes. *Journal of Plant Nutrition*, *47*(19), 3701-3720.
17. Mehboob, N., Yasir, T. A., Ul-Allah, S., Nawaz, A., Ahmad, N., & Hussain, M. (2022). Interactive effect of boron application methods and boron-tolerant bacteria (Bacillus sp. MN54) improves nodulation, grain yield, profitability and biofortification of kabuli chickpea grown under irrigated and rainfed conditions. *Journal of Soil Science and Plant Nutrition*, *22*(4), 5068-5085.
18. Welch, R. M., & Graham, R. D. (2004). Breeding for micronutrients in staple food crops. *Journal of Experimental Botany, 55*(396), 353–364.