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EFFECT OF MICRONUTRIENTS ON YIELD AND QUALITY OF ONION SEED

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ABSTRACT

This investigation assessed the effect of micronutrients on the yield and quality of onion seed during the *rabi* season of 2024–2025 at the Vegetable Science Research Field, College of Horticulture, University of Horticultural Sciences, Bagalkot, Karnataka. The field experiment consisted of eight treatments laid out in a randomized block design with three replications. The treatments included the recommended dose of fertilizers along with individual soil applications of either iron sulphate or zinc sulphate (@ 10 kg ha^{-1} and 15 kg ha^{-1}, respectively) and combined soil applications of iron sulphate and zinc sulphate (@ 10 kg ha^{-1} and 15 kg ha^{-1} each) along with a foliar application of boron @ 100 ppm. The most effective treatment (T_8: soil application of iron sulphate @ 15 kg ha^{-1} and zinc sulphate @ 15 kg ha^{-1} with foliar boron @ 100 ppm) recorded a significantly higher seed yield (9.46 q ha^{-1}) and superior yield parameters compared to other treatments. This treatment also resulted in higher total nutrient concentration and nutrient uptake by the plant. Additionally, higher gross returns, net returns and benefit-cost (B:C) ratio were highest in T_8.

***Keywords* :** Micronutrients, Yield, Quality, Onion

Introduction

Onion is among the most commonly grown and consumed vegetables globally. It is believed to have its origin in Central Asia and the Mediterranean region, as noted by McCollum (1976). Classified under the family Amaryllidaceae, the onion has a basic chromosome number of X = 8, making its diploid number 2n = 16. This herbaceous plant is cultivated as an annual for producing bulbs and as a biennial for seed generation. The bulb which is the edible portion is a modified stem.

There are two primary techniques for producing onion seed: the seed-to-seed method and the bulb to seed method. Among these, the bulb-to-seed method is generally preferred. In this approach bulbs are cultivated during the first season and in the following season healthy and uniform bulbs are replanted specifically for seed production.

India has an annual requirement of approximately 9,300 tonnes of onion seed, which is primarily supplied by private companies and farmers using their own produced seeds. (Bedemo *et al.*, 2014). However, seeds from this sector often fall short of quality standards, with issues such as low germination rates and lack of genetic purity, ultimately impacting poor crop productivity. Moreover, due to the short shelf life of onion seeds and their tendency to lose viability within a year, farmers often use twice the recommended seed rate to secure enough seedlings leading to increased production costs. Hence, it is essential to boost the availability of quality seed.

The yield and quality of onion seeds are influenced by several factors, among which the application of micronutrients plays a significant role. Although required by plants in small quantities micronutrients are essential for various metabolic and cellular functions. They are actively involved in key physiological processes such as cell wall formation, respiration, photosynthesis, chlorophyll synthesis, enzyme activation and auxin synthesis (Brady, 1990). the application of micronutrients either through foliar spray or soil application is essential. Among these zinc, boron and iron have gained particular significance in onion cultivation. Although the use of micronutrients has shown considerable potential in onion seed production existing research on this topic remains limited and fragmented. Hence, keeping this in view the present study was undertaken to evaluate the effect of micronutrients on the yield and quality of onion seed

Materials and Method

The current study was conducted during the *rabi* season of 2024–2025 at the vegetable science research field, College of Horticulture, University of Horticultural Sciences Bagalkot, Karnataka. The field experiment included the total of eight treatments laid out in a randomized block design with three replications. Onion bulbs measuring 4 to 6 cm in diameter and weighing between 50 and 60 grams were selected. The top portion of each bulb (3 to 5 mm) was removed and the bulbs were treated with Bavistin @ 1 g per litre of water for 10 minutes before sowing. The treated bulbs were then planted on one side of each ridge at a spacing of 45 cm × 15 cm.

The experiment consist of 8 treatments *Viz*., T_1 - RDF (FYM @ 15t ha^{-1}, N:P: K::100: 50:50 kg ha^{-1}), T_2 - RDF + foliar application of boron 100 ppm, T_3 - RDF + soil application of iron sulphate 10 kg ha^{-1} + foliar application of boron 100 ppm, T_4 - RDF + soil application of zinc sulphate 10 kg ha^{-1} + foliar application of boron 100 ppm, T_5 - RDF + soil application of iron sulphate 15 kg ha^{-1} + foliar application of boron 100 ppm, T_6-RDF + soil application of zinc Sulphate 15 kg ha^{-1} + foliar application boron 100 ppm, T_7-RDF + soil application of iron sulphate 10 kg ha^{-1} + soil application of zinc sulphate 10 kg ha^{-1} + foliar application of boron 100 ppm, T_8-RDF + soil application of iron sulphate 15 kg ha^{-1} + soil application of zinc sulphate 15 kg ha^{-1} + foliar application of boron 100 ppm. Farmyard manure was evenly incorporated into the soil at a rate of 15 tonnes ha^{-1}, two weeks prior to sowing. The recommended NPK fertilizer dose was applied across all treatments. At the time of sowing, 50 per cent of the nitrogen along with the full doses of phosphorus and potassium were applied to the respective plots

The growth parameters like plant height, number of leaves, days to 50 per cent bolting, umbel diameter (mm) and dry matter per plant (g) were recorded. Plant height was recorded with the help of a measuring scale, time required for 50 per cent of the plants in each plot to initiate bolting measured from the date of bulb planting was monitored and recorded, dry matter per plant (g plant^{-1}) was calculated based on plant density after five randomly selected plants from each plot were uprooted, cleaned and plant parts oven-dried at 65–70 °C until a constant weight was obtained.

Yield parameters including number of seeds per umbel, 1000-seed weight, seed yield per umbel (g), per plant (g) and per hectare(q) were recorded. A random sample of 1000 seeds from each treatment plot were weighed using a physical balance to determine the 1000-seed weight. Seeds from umbels of selected plants were collected and weighed to calculate average seed weight per umbel and per plant. Seed yield per hectare was calculated by extrapolating plot yields using the appropriate conversion factor and expressed in quintals.

Germination percentage, seedling vigour index I & II, root to shoot ratio and seedling length were evaluated as key quality parameters of onion seed. Germination performance of seeds from each treatment was assessed using 100 seeds placed in petri dishes lined with moist tissue paper. Seedling length was measured as the combined root and shoot length of 10 randomly selected seedlings per treatment and the mean value was recorded in centimetres. Dried seedlings were separated into roots and shoots to measure their dry weights and the root-to-shoot ratio was computed to assess biomass allocation. Seedling vigour was evaluated using two indices The equation to calculate Seedling vigour index is as follows:

Vigour index I = Germination percentage × [Root length (cm) + Shoot length (cm)]

Vigour index II = Germination percentage x Seedling dry weight (mg)

Nutrient uptake by leaves, bulb and roots was calculated by multiplying the oven-dried weight (65°C for 48 h) of each part with its respective nutrient concentration and expressed per hectare as kg ha^{-1} for macronutrients and g ha^{-1} for micronutrients.

The mathematical equation to calculate it is as follows.

$$\text{Macronutrient Uptake (kg ha}^{-1}) = \frac{\text{Dry matter kg ha}^{-} \text{ x Nutrient content \%}}{100}$$

$$\text{Micronutrient Uptake (g ha}^{-1}\text{)} = \frac{\text{Dry matter kg ha}^{-1} \text{ x Nutrient content \%}}{1000}$$

Result and Discussion

The treatment comprising soil application of iron sulphate @ 15 kg ha^{-1} and zinc sulphate @ 15 kg ha^{-1} along with a foliar application of boron @ 100 ppm had a significant impact on the growth parameters resulting maximum plant height (62.05cm), number of leaves (32.24), days to 50% bolting (60DAS), umbel diameter (75.95mm), dry matter per plant (10.63 g $plant^{-1}$).

Plant height at 90 DAS varied significantly with micronutrient application (Table1). The combined soil and foliar application of Zn + B + Fe (T_8) recorded the tallest plants (62.05 cm), which was statistically on par with the soil and foliar application of Zn + B (T_6, 60.20 cm). The superiority of T_8 may be attributed to the synergistic role of Fe, Zn and B in enhancing chlorophyll synthesis, enzyme activity, hormonal regulation and cell elongation, thereby promoting vegetative growth. Similar findings were reported by Pramanik and Tripathy (2017), Shinde *et al.* (2016), Jana and Mukhopadhyay (2002), More *et al.* (2025) and Khatemenla *et al.* (2017). Although T_8 showed a slight advantage, its statistical similarity with T_6 suggests that Zn + B application may be a more cost-effective option where soil Fe levels are sufficient.

The number of leaves per plant at 90 DAS varied significantly with micronutrient application (Table1). The combined soil application of Fe and Zn with foliar application of B (T_8) recorded the highest leaf number (32.24), which was statistically on par with soil application of Zn + foliar B (T_6: 31.12). The lowest number of leaves was observed in the control (RDF alone). The superior performance of T_8 and T_6 may be attributed to the synergistic role of Zn, B and Fe in enhancing leaf initiation and expansion. Zinc promotes auxin synthesis and enzyme activation, boron aids in cell wall development and sugar transport and iron supports chlorophyll formation and photosynthesis. Since T_6 was statistically similar to T_8, Zn + B application may be sufficient under adequate soil Fe conditions. Similar results were reported by Pramanik and Tripathy (2017), Shinde *et al.* (2016), More and Varma (2025) and Khatemenla *et al.* (2017).

The number of days required for 50% bolting varied significantly among treatments (Table1). The control (T_1) took the longest time (65.00 DAS) to reach 50% bolting, while the combined soil application of Fe and Zn with foliar application of B (T_8) recorded the shortest period (60.00 DAS), which was statistically on par with T_6 (Zn + B: 61.67 DAS) and T_7 (61.00 DAS). The earlier bolting observed in micronutrient-treated plots indicates their role in accelerating the reproductive transition. This effect may be attributed to the influence of Zn, B and Fe on hormonal regulation, enzyme activation and photosynthetic efficiency. Zinc promotes enzyme activation and hormone regulation; boron supports meristematic activity and sugar translocation and iron enhances chlorophyll content and photosynthesis. The statistical similarity of T_6 and T_8 suggests that where soil Fe is adequate, Zn + B application alone may be sufficient to induce timely bolting. Similar results were reported by More and Varma (2025) and Zaman *et al.* (2019).

Umbel diameter of onion varied significantly with micronutrient application (Table1). The largest umbels (75.95 mm) were recorded in T_8 (soil application of Fe and Zn + foliar B), which was statistically on par with T_6 (Zn + B: 75.08 mm). The smallest umbels were observed in the control (65.31 mm). The superiority of T_8 may be attributed to the synergistic role of Zn, B and Fe in enhancing reproductive growth. Zinc promotes enzyme activation and auxin synthesis, boron improves cell wall formation and carbohydrate transport and iron supports chlorophyll synthesis and photosynthesis, ensuring adequate assimilate supply. Since T_6 was statistically similar to T_8, Zn + B alone may sufficiently meet the crop's physiological needs for umbel development, with Fe offering only marginal benefits. Thus, Zn + B application appears to be a more cost-effective option. Similar findings were reported by Manna *et al.* (2017), Durgude *et al.* (2024), Miah *et al.* (2020) and Hasan (2024).

Dry matter accumulation per plant increased significantly with micronutrient application (Table1). The highest dry matter (10.63 g $plant^{-1}$) was recorded in T_8 (soil application of Fe + Zn with foliar B), which was significantly superior to all other treatments. T_6 (Zn + B) recorded the next highest value (10.05 g $plant^{-1}$) but was not statistically on par with T_8, indicating that the combined application of Zn, B and Fe is essential for maximum biomass production. Iron enhances chlorophyll synthesis, electron transport and energy metabolism; zinc activates key enzymes and supports auxin regulation; and boron facilitates sugar transport and cell wall formation. Their combined effect improves both photosynthetic efficiency and assimilate storage, resulting in greater dry matter accumulation. Similar synergistic effects of Zn, B and Fe on biomass production in onion were reported by Khatemenla *et al.* (2017) and Hasan (2024).

Application of micronutrients had a significant effect on yield parameters like seeds per umbel (1,248 seeds), 1000 seed weight (3.00 g), seed yield per umbel

(3.74g), seed yield per plant (10.07 g), seed yield per ha (9.46 q ha^{-1}).

The number of seeds per umbel varied significantly with micronutrient application (Table2). The control (T_1) produced the fewest seeds (1,163), while the highest number (1,248) was recorded in T_8 (soil application of Fe + Zn with foliar B), which was statistically on par with T_6 (Zn + B). The superior performance of T_8 and T_6 can be attributed to the synergistic effects of Zn, B and Fe in improving flower development, pollination and seed set. Zinc enhances pollen fertility and enzyme activity related to cell division, boron promotes pollen tube growth and fertilization and iron supports photosynthesis and assimilate supply to developing seeds. Since T_6 produced seed numbers comparable to T_8, Zn + B alone may be sufficient where soil Fe is adequate. Similar results were reported by Manna *et al.* (2017), Durgude *et al.* (2024), Zaman *et al.* (2019), Arunkumar *et al.* (2021) and Haque *et al.* (2014).

The 1000-seed weight was significantly influenced by micronutrient application (Table 2). The lowest value (2.80 g) was recorded in the control (RDF alone), while the combined soil application of Fe and Zn with foliar B (T_8) produced the highest 1000-seed weight (3.00 g), which was statistically on par with T_6 (Zn + B: 2.97 g). The increase in seed weight under T_8 and T_6 may be attributed to the synergistic effects of Zn, B and Fe in enhancing physiological and reproductive processes. Zinc promotes auxin synthesis, enzyme activation and pollen viability; boron supports pollen tube growth, carbohydrate metabolism and assimilate transport; and iron improves chlorophyll content and photosynthetic rate, ensuring greater assimilate supply to developing seeds. Since T_6 was statistically similar to T_8, it indicates that under the existing soil conditions, Fe was not a limiting factor and Zn + B alone were sufficient to optimize seed development. Similar findings were reported by Durgude *et al.* (2024), Manna *et al.* (2017), Haque *et al.* (2014), Arunkumar *et al.* (2021) and Zaman *et al.* (2019).

The weight of seeds per umbel was significantly influenced by micronutrient application (Table 2). The lowest seed weight (3.26 g) was recorded in the control (RDF alone), while the highest (3.74 g) was observed in T_8 (soil application of Fe + Zn with foliar B), which was statistically on par with T_6 (Zn + B: 3.67 g). The increase in seed weight under micronutrient treatments may be attributed to the synergistic role of Zn, B and Fe in enhancing reproductive development. Zinc promotes auxin synthesis, enzyme activation and pollen viability; boron supports pollen germination, pollen tube elongation and carbohydrate transport to developing seeds; and iron enhances chlorophyll content and photosynthetic efficiency, ensuring greater assimilate supply. The statistical similarity of T_6 and T_8 indicates that under the existing soil conditions, Fe was not a limiting factor and Zn + B alone provided most of the benefit for seed development, with Fe contributing only marginal gains. Similar findings were reported by Manna *et al.* (2017), Durgude *et al.* (2024), Arunkumar *et al.* (2021), Zaman *et al.* (2019) and Haque *et al.* (2014).

Seed yield per plant was significantly influenced by micronutrient application (Table 2). The lowest yield (7.65 g $plant^{-1}$) was recorded in the control (RDF alone), while the highest (10.07 g $plant^{-1}$) was obtained in T_8 (soil application of Fe + Zn with foliar B), which was statistically on par with T_6 (Zn + B: 9.73 g $plant^{-1}$). The enhanced seed yield under micronutrient treatments can be attributed to the synergistic role of Zn, B and Fe in improving vegetative growth, flowering and seed development. Zinc promotes enzyme activation and auxin synthesis, enhancing pollen viability and seed set; boron supports pollen tube elongation, carbohydrate transport and assimilate partitioning; and iron increases chlorophyll content and photosynthetic efficiency, ensuring greater assimilate supply to developing seeds. The statistical similarity between T_6 and T_8 indicates that Zn + B alone were sufficient to achieve optimal seed yield under existing soil conditions, with Fe providing only a marginal additional benefit. Similar findings were reported by Zaman *et al.* (2019), Haque *et al.* (2014) and Arunkumar *et al.* (2021).

Seed yield per hectare was significantly influenced by micronutrient application (Table 3). The lowest yield (7.19 q ha^{-1}) was recorded in the control (RDF alone), while the highest (9.46 q ha^{-1}) was obtained in T_8 (soil application of Fe + Zn with foliar B), which was statistically on par with T_6 (Zn + B: 9.14 q ha^{-1}). The increase in seed yield under micronutrient treatments may be attributed to the combined role of Zn, B and Fe in enhancing reproductive development and seed filling. Zinc acts as a cofactor in enzyme systems and promotes auxin synthesis, boron improves pollen germination, pollen tube elongation and assimilate transport, while iron enhances chlorophyll formation and photosynthetic efficiency, ensuring a steady supply of assimilates to developing seeds. The statistical similarity of T_6 and T_8 suggests that Zn + B alone were sufficient to achieve near-maximum yield under existing soil conditions, with Fe contributing only marginal additional benefits. Similar results were reported by Haque *et al.* (2014), Arunkumar *et al.* (2021) and Zaman *et al.* (2019).

Application of micronutrients had a significant effect on quality parameters like germination % (84.80%), Seedling Vigour Index-I (1353.41), Seedling Vigour Index-II (1837.62), root-to-shoot ratio (0.835) and total seedling length (16.29 cm).

In this study, onion seed germination percentage did not differ significantly among the micronutrient treatments (Table 3). The control (RDF alone) recorded 80.20% germination, while the highest (84.80%) was observed in T_8 (combined soil and foliar application). Although slight numerical differences existed among treatments, they were statistically non-significant, indicating that micronutrient application during seed production had little direct effect on inherent seed viability under the experimental conditions. Germination is largely determined by genetic factors, seed maturity at harvest and storage conditions rather than nutrient management. Similar findings were reported by Khatemenla *et al.* (2017) and Arunkumar *et al.* (2021), who observed that micronutrient fertilization improved seed quality traits, such as seed weight, without significantly affecting germination percentage in onion.

Seedling Vigour Index-I (SVI-I) and II (SVI-II) were significantly influenced by micronutrient treatments (Table 3). The lowest values were recorded in the control (T_1: SVI-I = 1083.50, SVI-II = 1598.39), while T_8 (combined soil application of Fe + Zn with foliar B) produced the highest SVI-I (1353.41) and SVI-II (1837.62). Among individual soil applications with foliar B, T_6 (Zn + B) also showed high vigour (SVI-I = 1273.10, SVI-II = 1788.41) and was statistically on par with T_8 for SVI-II. Enhanced seedling vigour under micronutrient application is attributed to the synergistic effects of Zn, B and Fe on seed quality and early growth: Zn supports enzyme activation, auxin synthesis and protein metabolism; B improves cell wall formation, membrane integrity and carbohydrate translocation; and Fe enhances chlorophyll synthesis and photosynthetic efficiency. The comparable performance of T_6 and T_8 indicates that under the experimental soil conditions, Zn + B alone largely sufficed to enhance seedling vigour, with only marginal additional gains from Fe (Alloway, 2008; Fageria *et al.*, 2002; Arunkumar *et al.*, 2021).

The root-to-shoot ratio of onion plants showed slight, non-significant variation among treatments (Table 3), ranging from 0.801 in the control (T_1) to 0.835 in T_8 (combined soil and foliar micronutrients). Micronutrient application did not significantly affect biomass allocation between roots and shoots, indicating stable partitioning under the experimental soil conditions. Zinc, iron and boron primarily enhance enzymatic activity, chlorophyll formation and reproductive growth rather than altering the R:S ratio (Fageria *et al.*, 2002; Alloway, 2008; Arunkumar *et al.*, 2021), consistent with previous observations in onion (Khatemenla *et al.*, 2017).

Total seedling length varied significantly among micronutrient treatments (Table 3). The control (T_1) recorded the lowest length (13.43 cm), while T_8 (combined soil application of Fe + Zn with foliar B) achieved the highest (16.29 cm), significantly superior to other treatments. Among individual soil applications with foliar B, T_6 (Zn + B) showed a high seedling length (15.25 cm) and was statistically comparable to T_8. Enhanced seedling length under micronutrient treatments is attributed to the synergistic effects of Zn, B and Fe: Zn acts as a cofactor for enzymes involved in auxin synthesis and protein metabolism, promoting root and shoot elongation; B supports cell wall stability, membrane integrity, pollen germination and carbohydrate transport; and Fe enhances chlorophyll formation and photosynthesis, supplying energy for vigorous growth. The comparable performance of T_6 and T_8 suggests that soil Fe was adequate and Zn + B alone largely sufficed to improve seedling length (Alloway, 2008; Fageria *et al.*, 2002; Arunkumar *et al.*, 2021).

The micronutrients had a significant influence on nutrient uptake by onion plant. The highest values were recorded in treatment T_8. Total uptake of primary nutrients (N, P and K) by onion plants varied significantly with micronutrient treatment (Table 4). The highest nutrient uptake was observed in T_8 (combined soil application of Zn + Fe with foliar B), with 58.28 kg ha^{-1} N, 7.87 kg ha^{-1} P and 52.20 kg ha^{-1} K. Among individual soil applications with foliar B, T_6 recorded the next highest uptake (55.20 kg ha^{-1} N, 7.39 kg ha^{-1} P, 47.04 kg ha^{-1} K). The lowest uptake occurred in the control (T_1) with 32.58 kg ha^{-1} N, 5.07 kg ha^{-1} P and 24.08 kg ha^{-1} K. The superior nutrient accumulation under T_8 may be attributed to improved root growth and nutrient solubility from soil-applied Zn and Fe, along with enhanced photosynthesis, carbohydrate translocation and metabolic activity due to foliar B. Boron also supports cell wall formation and membrane stability, facilitating efficient NPK uptake and translocation. These results align with previous findings in onion and garlic under combined micronutrient management (Prusty *et al.*, 2020; Singh *et al.*, 2019; Kumar *et al.*, 2018).

Total uptake of secondary nutrients (Ca, Mg and S) by onion plants varied significantly with micronutrient treatment (Table 4). The highest uptake was recorded in T_8 (combined soil application of Zn + Fe with foliar B), with 17.22 kg ha^{-1} Ca, 9.36 kg ha^{-1} Mg and 7.42 kg ha^{-1} S. Among individual soil applications with foliar B, T_6 recorded the next highest uptake (15.81 kg ha^{-1} Ca, 8.83 kg ha^{-1} Mg, 6.56 kg ha^{-1} S), while the lowest values occurred in the control (T_1: 10.76 kg ha^{-1} Ca, 6.17 kg ha^{-1} Mg, 4.66 kg ha^{-1} S). Superior nutrient accumulation in T_8 may be attributed to boron-enhanced Ca transport, Fe and Zn-stimulated photosynthetic enzyme activity increasing Mg demand and sulphate forms of Fe and Zn supporting S uptake. These results are consistent with previous reports in onion (Khatemenla *et al.*, 2017) and mustard (Najar & Bhat, 2012).

Total uptake of micronutrients (Fe, Zn, Mn, Cu and B) by onion plants varied significantly with different micronutrient treatments (Table 4). The highest uptake of Fe (312.51 g ha^{-1}), Mn (84.77 g ha^{-1}), B (26.69 g ha^{-1}) and Cu (15.43 g ha^{-1}) was recorded in T_8 (combined soil application of Zn + Fe with foliar B), while T_6 (soil Zn + foliar B) recorded the highest Zn uptake (137.40 g ha^{-1}). The lowest micronutrient uptake occurred in the control (T_1: 100.56 g ha^{-1} Fe, 54.28 g ha^{-1} Zn, 65.94 g ha^{-1} Mn, 11.48 g ha^{-1} Cu, 13.80 g ha^{-1} B). Enhanced uptake under T_8 may be attributed to soil-applied micronutrients maintaining a steady rhizosphere pool, while foliar B corrected transient deficiencies and stimulated metabolic demand. Boron also regulates root development and membrane permeability, improving ion transport. Higher accumulation of Fe, Zn and Mn reflects enhanced enzymatic and redox activity, whereas increased Cu and B support structural integrity and reproductive growth. Integrating soil application with foliar B thus creates a synergistic pathway for micronutrient acquisition and mobilization. Similar trends in Zn, B and Fe uptake under micronutrient management have been reported in onion (Trivedi & Dhumal, 2013; Ballabh *et al.*, 2013).

The micronutrients had a significant influence on the economics of onion seed production. The highest values were recorded in treatment T_8.

The economics of onion seed production was significantly influenced by micronutrient application (Table 5). Seed yield ranged from 719 kg ha^{-1} in the control (T_1: RDF alone) to 946 kg ha^{-1} in T_8 (soil application of Fe + Zn with foliar B). Although the cost of cultivation varied slightly, being lowest in T_1 (Rs. 3,82,960 ha^{-1}) and highest in T_8 (Rs. 3,88,610 ha^{-1}), the increased seed yield under micronutrient treatments substantially improved gross and net returns. The highest gross return was recorded in T_8 (Rs. 9,46,000 ha^{-1}), followed by T_6 (Rs. 9,14,000 ha^{-1}), while the net return was maximum in T_8 (Rs. 5,57,390 ha^{-1}), followed by T_6 (Rs. 5,27,390 ha^{-1}) and lowest in T_1 (Rs. 3,36,040 ha^{-1}). The benefit:cost ratio followed a similar trend, with T_8 achieving the highest (2.43) and T_1 the lowest (1.88), indicating superior economic viability of integrated micronutrient application. Enhanced returns in T_8 and T_6 are attributed to the synergistic effects of Zn, B and Fe on vegetative growth, flowering, pollination and seed set, with Fe further improving chlorophyll content and photosynthetic efficiency. Despite a slight increase in cultivation cost, the additional yield and net returns make combined soil and foliar micronutrient application both agronomically and economically advantageous (Haque *et al.*, 2014; Arunkumar *et al.*, 2021; Zaman *et al.*, 2019).

Conclusion

The study revealed that combined soil application of $FeSO_4$ and $ZnSO_4$ with foliar boron (T_8) consistently outperformed other treatments in growth, yield, seed quality and nutrient uptake. However, soil application of $ZnSO_4$ with foliar boron (T_6) produced comparable results, with no significant differences from T_8 for most parameters. Therefore, in iron-deficient soils, T_8 is recommended to maximize productivity and nutrient use efficiency, as iron is critical for plant growth. In soils with adequate iron, T_6 offers a more economical option, delivering similar growth, yield and seed quality with lower input costs. Selection between T_8 and T_6 should thus be based on soil iron status and economic considerations to optimize onion seed production efficiently.

Table 1: Effect of micronutrients on growth parameters of onion

	Plant height @ 90 DAS	No. of leaves @ 90 DAS	Days to 50% bolting	Umbel diameter (mm)	Dry matter per plant (g)
T_1	43.36	22.30	65.00	65.31	6.65
T_2	45.21	24.23	63.00	70.64	7.55
T_3	47.65	25.54	62.33	71.10	8.20
T_4	53.82	28.50	62.00	72.03	9.50

T_5	49.90	27.41	62.67	71.79	8.59
T_6	60.20	31.12	61.67	75.08	10.05
T_7	56.06	30.00	61.00	73.15	9.49
T_8	62.05	32.24	60.00	75.95	10.63
S. Em ±	**0.67**	**0.51**	**0.67**	**1.33**	**0.15**
C.D. at 5%	**2.03**	**1.55**	**2.02**	**4.02**	**0.46**

T_1 – RDF (FYM @ 15 t ha^{-1}, N:P: K::100: 50:50 kg ha^{-1})

T_2 - RDF + FA of Boron 100 ppm 30, 60, 90 DAS

T_3 - RDF + SA of Iron sulphate 10 kg ha^{-1} + FA of Boron 100 ppm 30, 60, 90 DAS

T_4 - RDF + SA of Zinc Sulphate 10 kg ha^{-1} + FA of Boron 100 ppm 30, 60, 90 DAS

T_5 - RDF + SA of Iron Sulphate 15 kg ha^{-1} + FA Boron 100 ppm 30, 60, 90 DAS

T_6 - RDF + SA of Zinc Sulphate 15 kg ha^{-1} + FA of Boron 100 ppm 30, 60, 90 DAS

T_7 - RDF + SA of Iron sulphate 10 kg ha^{-1} + SA of Zinc Sulphate 10 kg ha^{-1} + FA of Boron 100 ppm 30, 60, 90 DAS

T_8- RDF + SA of Iron sulphate 15 kg ha^{-1} + SA of Zinc Sulphate15 kg ha^{-1} + FA of Boron 100 ppm 30, 60, 90 DAS

Table 2: Effect of micronutrients on yield parameters of onion

	No. of seeds per umbel	Weight of seeds per umbel (g)	Yield of seeds per plant (g)	Yield of seeds per ha (q)	weight of 1000 seeds (g)
T_1	1163	3.26	7.65	7.19	2.80
T_2	1175	3.32	8.01	7.52	2.83
T_3	1187	3.39	8.28	7.77	2.86
T_4	1212	3.53	8.93	8.39	2.91
T_5	1199	3.46	8.62	8.09	2.89
T_6	1236	3.67	9.73	9.14	2.97
T_7	1224	3.60	9.36	8.79	2.94
T_8	1248	3.74	10.07	9.46	3.00
S. Em ±	**14.26**	**0.05**	**0.11**	**0.11**	**0.03**
C.D. at 5%	**43.26**	**0.16**	**0.34**	**0.33**	**0.08**

Table 3: Effect of micronutrients on quality parameters of onion

	Germination %	Seedling Vigour Index-I (SVI-I)	Seedling Vigour Index-II	Root to Shoot Ratio	Total Seedling length (cm)
T_1	80.20	1083.50	1598.39	0.801	13.43
T_2	81.01	1140.62	1649.36	0.804	14.21
T_3	81.70	1165.86	1668.31	0.806	13.75
T_4	82.40	1202.22	1726.28	0.812	13.90
T_5	82.00	1185.72	1693.30	0.807	14.41
T_6	84.20	1273.10	1788.41	0.821	15.25
T_7	83.60	1230.59	1759.78	0.816	14.30
T_8	84.80	1353.41	1837.62	0.835	16.29
S. Em ±	**1.08**	**14.08**	**24.14**	**0.01**	**0.24**
C.D. at 5%	**NS**	**42.72**	**73.23**	**NS**	**0.73**

Table 4: Effect of micronutrients on total nutrient uptake

	N uptake (kg ha^{-1})	P Uptake (kg ha^{-1})	K Uptake (kg ha^{-1})	Ca uptake (kg ha^{-1})	Mg uptake (kg ha^{-1})	S uptake (kg ha^{-1})	Fe uptake (g ha^{-1})	Zn uptake (g ha^{-1})	Mn uptake (g ha^{-1})	Cu uptake (g ha^{-1})	B uptake (g ha^{-1})
T_1	32.58	5.07	24.08	10.76	6.17	4.66	100.56	54.28	65.94	11.48	13.80
T_2	36.67	5.58	28.49	11.53	6.81	5.15	103.84	58.79	72.07	13.35	22.21
T_3	41.38	5.86	31.09	12.31	7.18	5.53	240.85	63.42	77.27	13.21	22.28
T_4	48.87	6.45	39.44	13.94	7.91	5.93	117.80	110.96	79.47	13.17	24.59
T_5	44.59	6.13	34.68	13.20	7.45	5.94	287.47	68.20	76.36	13.57	22.19
T_6	55.20	7.39	47.04	15.81	8.83	6.56	122.70	142.49	80.99	15.40	25.48
T_7	51.22	6.65	44.19	14.46	8.46	6.86	255.49	104.56	79.57	14.60	24.33
T_8	58.28	7.87	52.20	17.22	9.36	7.42	312.51	137.40	84.77	15.43	26.69
S.E.m	**0.76**	**0.07**	**0.45**	**0.25**	**0.14**	**0.09**	**4.09**	**1.11**	**0.91**	**0.19**	**0.31**
CD @ 5%	**2.29**	**0.23**	**1.37**	**0.75**	**0.43**	**0.26**	**12.40**	**3.36**	**2.75**	**0.58**	**0.94**

Table 5: Economics of onion seed production as influenced by the application of micronutrients

	Yield ha^{-1}	Cost of cultivation Rs ha^{-1}	gross return Rs ha^{-1}	Net return Rs ha^{-1}	B:C ratio
T_1	7.19	382960	719000	336040	1.88
T_2	7.52	383810	752000	368190	1.96
T_3	7.77	385410	777000	391590	2.02
T_4	8.39	385410	839000	453590	2.18
T_5	8.09	386610	809000	422390	2.09
T_6	9.14	386610	914000	527390	2.36
T_7	8.79	387810	879000	491190	2.27
T_8	9.46	388610	946000	557390	2.43

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