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Comparative evaluation of soil and foliar micronutrient application for enhancing productivity, quality and nutrient use efficiency of groundnut (*Arachis hypogaea* L.) in sandy soils

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Abstract

Micronutrient deficiencies, particularly zinc (Zn), iron (Fe), and boron (B), are major constraints to groundnut (*Arachis hypogaea* L.) production in sandy soils due to low nutrient retention and poor nutrient availability. A field experiment was conducted during the Rabi season of 2024- 2025 to compare the effectiveness of soil and foliar application of micronutrients on growth, yield, quality, and nutrient use efficiency of groundnut. Ten treatments comprising control, farmyard manure (FYM), individual and combined soil applications of Zn, Fe, and B, and corresponding foliar applications were evaluated in a randomized block design with three replications. Growth, yield attributes, yield, and quality parameters were recorded and analyzed statistically. Application of FYM @ 10 t ha⁻¹ significantly improved plant growth, SPAD chlorophyll readings, nodulation, dry matter accumulation, and yield attributes, resulting in the highest pod yield (2506 kg ha⁻¹), kernel yield (1864 kg ha⁻¹), protein content (24.85%), oil content (49.77%), and oil yield (928.24 kg ha⁻¹). Among the inorganic micronutrient treatments, combined soil application of ZnSO₄, FeSO₄, and borax consistently produced superior growth, yield, and quality compared with their individual soil or foliar applications, while combined foliar application ranked next. The study demonstrated that integrated nutrient management involving FYM and balanced micronutrient application effectively enhanced productivity, quality, and nutrient use efficiency of groundnut in sandy soils and can be recommended for sustainable groundnut cultivation under micronutrient-deficient conditions.

Keywords: Groundnut, zinc, iron, boron, soil application, foliar application, sandy soils, nutrient use efficiency, quality, yield

Introduction

Groundnut (*Arachis hypogaea* L.) is one of the most important oilseed and food legume crops cultivated worldwide because of its high oil (45-50%) and protein (20-30%) content, making it an important source of edible oil, nutrition, and farm income. In India, groundnut is predominantly grown under rainfed and light-textured soils, where productivity is frequently constrained by low soil fertility, poor organic matter content, and widespread micronutrient deficiencies. Sandy soils are particularly susceptible to nutrient losses owing to their low cation exchange capacity and poor moisture-holding ability, resulting in reduced nutrient availability and lower crop productivity. Consequently, balanced nutrient management has become essential for sustaining groundnut production in these fragile agroecosystems (Vasuki & Sudhalakshmi, 2022; Abhigna *et al.*, 2021; Rabari *et al.*, 2024) [17, 1, 13]. Among the essential micronutrients, zinc (Zn), iron (Fe), and boron (B) play indispensable roles in plant growth and development. Zinc regulates enzyme activity, protein synthesis, chlorophyll formation, and auxin metabolism, whereas iron is essential for photosynthesis, respiration, and chlorophyll biosynthesis. Boron is involved in cell wall formation, pollen viability, fertilization, carbohydrate transport, and seed development. Deficiency of these micronutrients adversely affects nodulation, photosynthetic efficiency, reproductive development, pod formation, and kernel quality, ultimately reducing yield and nutrient use efficiency in groundnut (Haneena *et al.*, 2021; Sai Venkatesh *et al.*, 2024; Hadole *et al.*, 2024) [6, 14, 5].

Micronutrients can be supplied through soil or foliar application, each having distinct advantages. Soil application provides a continuous nutrient supply throughout crop growth, whereas foliar application offers rapid correction of nutrient deficiencies during critical growth stages with higher nutrient use efficiency. Previous studies have demonstrated significant improvements in growth, yield, nutrient uptake, and quality following soil or foliar application of Zn, Fe, and B, either individually or in combination. However, comparative information on the effectiveness of these application methods under sandy soil conditions remains limited, particularly with respect to productivity, quality, and nutrient use efficiency (Dadhich & Yadav, 2021; Ghadiali *et al.*, 2023; Jagasia *et al.*, 2024; Patel *et al.*, 2024; Jegadeeswari *et al.*, 2025) [2, 3, 8, 11, 9]. Therefore, the present investigation was undertaken to compare the effectiveness of soil and foliar application of zinc, iron, and boron, individually and in combination, for improving growth, productivity, quality, and nutrient use efficiency of groundnut cultivated in sandy soils.

Materials and Methods

A field experiment was conducted during the Rabi season of 2024-2025 at the Research Farm, School of Agriculture Science, Technology and Research, Sardar Patel University, Balaghat, Madhya Pradesh, India. The experimental site comprised sandy soil with low native fertility. The experiment was laid out in a Randomized Block Design (RBD) with ten treatments and three replications. Recommended agronomic practices were followed uniformly throughout the crop growth period. The treatments consisted of control (T₁), farmyard manure (FYM) @ 10 t ha⁻¹ (T₂), soil application of ZnSO₄ @ 16 kg ha⁻¹ (T₃), FeSO₄ @ 10 kg ha⁻¹ (T₄), borax @ 10 kg ha⁻¹ (T₅), combined soil application of ZnSO₄ + FeSO₄ + borax (T₆), foliar application of ZnSO₄ @ 0.2% (T₇), FeSO₄ @ 0.5% (T₈), borax @ 0.25% (T₉), and combined foliar application of ZnSO₄ @ 0.2% + FeSO₄ @ 0.5% + borax @ 0.25% (T₁₀). Soil-applied micronutrients were applied as basal, whereas foliar sprays were imposed at 30 and 60 days after sowing (DAS). The treatment details are presented in Table 1. Growth observations, including plant height, number of branches plant⁻¹, SPAD chlorophyll reading, leaf area index, nodules plant⁻¹, nodule dry weight, and dry matter production, were recorded at appropriate crop growth stages. Phenological observations comprised days to 50% flowering and days to maturity, while yield attributes included developed pods plant⁻¹, total pods plant⁻¹, kernels pod⁻¹, and 100-kernel weight. At harvest, pod yield, kernel yield, haulm yield, harvest index, shelling percentage, protein content, oil content, and oil yield were recorded using standard procedures. Nitrogen content was determined by the modified Kjeldahl method (Jackson, 1973) [7], phosphorus by the vanado-molybdate yellow colour method (Jackson, 1973) [7], potassium by flame photometry (Jackson, 1973) [7], zinc and iron by atomic absorption spectrophotometry (Lindsay & Norvell, 1978) [10], and boron by the curcumin method (Tandon, 2005) [16]. Nutrient uptake was computed by multiplying nutrient concentration with the corresponding dry matter or economic yield as described in the standard procedures. The data were subjected to analysis of variance (ANOVA) appropriate for a Randomized Block Design as described by Gomez and Gomez (1984) [4]. Treatment means were compared using

the critical difference (CD) test at the 5% probability level. All the analysis were performed using Rstudio (Posit team, 2025) [12].

Results and Discussion

Growth attributes of groundnut were significantly influenced by different micronutrient application methods (Table 2). Application of FYM @ 10 t ha⁻¹ (T₂) recorded the highest growth, followed by the combined soil application of ZnSO₄ + FeSO₄ + borax (T₆). These treatments significantly increased plant height, SPAD chlorophyll reading, nodulation, leaf area index, and dry matter production compared with the control, whereas individual foliar applications produced comparatively lower responses. Improved growth under FYM and combined soil micronutrient application could be attributed to enhanced nutrient availability, better root development, increased chlorophyll synthesis, and improved physiological activity. Similar improvements in vegetative growth following balanced micronutrient application have been reported by Abhigna *et al.* (2021) [1], Vasuki and Sudhalakshmi (2022) [17], Hadole *et al.* (2024) [5], and Rabari *et al.* (2024) [13].

Micronutrient application significantly influenced yield attributes of groundnut, whereas days to 50% flowering and days to maturity remained statistically unaffected (Table 3). Application of FYM @ 10 t ha⁻¹ (T₂) recorded the highest number of developed pods plant⁻¹, total pods plant⁻¹ and 100-kernel weight, followed by the combined soil application of ZnSO₄ + FeSO₄ + borax (T₆). In contrast, the control treatment produced the lowest values for all yield attributes. The improvement in pod development and kernel weight under integrated nutrient management indicates enhanced assimilate partitioning and reproductive efficiency resulting from balanced micronutrient nutrition. The superior performance of FYM and combined soil application may be attributed to improved nutrient availability, enhanced photosynthetic activity, efficient carbohydrate translocation and better pollen viability, which collectively promoted pod formation and seed filling. Zinc, iron and boron play complementary roles in enzyme activation, chlorophyll synthesis and reproductive development, thereby improving sink strength and kernel development. Similar enhancements in yield attributes following balanced micronutrient application have been reported by Vasuki and Sudhalakshmi (2022) [17], Hadole *et al.* (2024) [5], Sai Venkatesh *et al.* (2024) [14], and Shashank *et al.* (2024) [15].

Micronutrient application significantly improved pod yield, kernel yield, haulm yield, shelling percentage, protein content, oil content, and oil yield compared with the control (Tables 4 and 5). Among all treatments, FYM @ 10 t ha⁻¹ (T₂) recorded the highest pod yield (2506 kg ha⁻¹), kernel yield (1864 kg ha⁻¹), shelling percentage (74.48%), protein content (24.85%), oil content (49.77%), and oil yield (928.24 kg ha⁻¹), followed by the combined soil application of ZnSO₄ + FeSO₄ + borax (T₆). Although harvest index did not differ significantly among treatments, balanced micronutrient application markedly enhanced both yield and quality parameters over the control. The increased productivity under FYM and combined soil application can be attributed to improved nutrient availability, enhanced photosynthetic efficiency, greater assimilate translocation to developing pods, and better nutrient uptake throughout the crop growth period. Improved shelling percentage, protein

content, and oil content further indicate the beneficial role of balanced micronutrient nutrition in enhancing kernel development and biochemical composition. Similar positive responses of groundnut to integrated application of Zn, Fe, and B have been reported by Rabari *et al.* (2024) ^[13], Patel

et al. (2024) ^[11], Hadole *et al.* (2024) ^[5], Jegadeeswari *et al.* (2025) ^[9], and Wahane *et al.* (2024) ^[18], who also observed significant improvements in yield, quality, and nutrient use efficiency following balanced micronutrient management.

Table 1: Details of treatments from in the experiment

Treatment	Treatment details
T ₁	Control
T ₂	Farmyard manure (FYM) @ 10 t ha ⁻¹
T ₃	Soil application of zinc sulphate (ZnSO ₄) @ 16 kg ha ⁻¹ as basal
T ₄	Soil application of ferrous sulphate (FeSO ₄) @ 10 kg ha ⁻¹ as basal
T ₅	Soil application of borax @ 10 kg ha ⁻¹ as basal
T ₆	Soil application of ZnSO ₄ @ 16 kg ha ⁻¹ + FeSO ₄ @ 10 kg ha ⁻¹ + borax @ 10 kg ha ⁻¹ as basal
T ₇	Foliar application of ZnSO ₄ @ 0.2% at 30 and 60 DAS
T ₈	Foliar application of FeSO ₄ @ 0.5% at 30 and 60 DAS
T ₉	Foliar application of borax @ 0.25% at 30 and 60 DAS
T ₁₀	Foliar application of ZnSO ₄ @ 0.2% + FeSO ₄ @ 0.5% + borax @ 0.25% at 30 and 60 DAS

Table 2: Effect of soil and foliar application of micronutrients on growth attributes of groundnut

Treatments	Plant height at harvest (cm)	Branches plant ⁻¹ at harvest	SPAD at harvest	Leaf area index at harvest	Nodules plant ⁻¹ (90 DAS)	Nodule dry weight (g plant ⁻¹) (90 DAS)	Dry matter production at harvest (kg ha ⁻¹)
T ₁ : Control (RDF)	27.9	5.13	20.28	1.07	54.97	0.179	4224
T ₂ : RDF + FYM @ 10 t ha ⁻¹	41.6	8.43	39.39	1.83	85.70	0.294	5845
T ₃ : RDF + Soil application of ZnSO ₄ @ 16 kg ha ⁻¹	37.6	7.40	34.90	1.58	77.33	0.280	5229
T ₄ : RDF + Soil application of FeSO ₄ @ 10 kg ha ⁻¹	37.1	7.30	34.58	1.56	76.93	0.270	5191
T ₅ : RDF + Soil application of borax @ 10 kg ha ⁻¹	38.4	7.77	35.02	1.64	79.53	0.280	5324
T ₆ : RDF + Soil application of ZnSO ₄ + FeSO ₄ + borax	40.0	8.33	37.63	1.76	82.93	0.285	5584
T ₇ : RDF + Foliar ZnSO ₄ @ 0.2%	34.2	6.03	24.29	1.36	66.67	0.210	4910
T ₈ : RDF + Foliar FeSO ₄ @ 0.5%	33.8	5.80	23.08	1.29	62.93	0.209	4742
T ₉ : RDF + Foliar borax @ 0.25%	34.7	6.40	25.93	1.44	70.80	0.220	4969
T ₁₀ : RDF + Foliar ZnSO ₄ + FeSO ₄ + borax	39.0	8.27	35.17	1.67	80.67	0.282	5163
SE±	2.15	0.38	2.19	0.09	4.39	0.015	252.72
CD @ 5%	6.41	1.14	6.65	0.27	13.06	0.047	750.88
CV (%)	10.2	9.4	12.2	10.4	10.3	10.9	8.5

Table 3: Effect of micronutrient application on phenology and yield attributes of groundnut

Treatments	Days to 50% flowering	Days to maturity	Developed pods plant ⁻¹ (At harvest)	Total pods plant ⁻¹	Kernels pod ⁻¹	100-kernel weight (g)
T ₁ Control (RDF)	24.33	100.00	7.37	7.47	1.90	27.58
T ₂ RDF + FYM @ 10 t ha ⁻¹	22.00	102.67	10.87	12.93	1.97	40.00
T ₃ RDF + Soil application of ZnSO ₄ @ 16 kg ha ⁻¹	22.67	101.00	9.90	11.27	1.90	36.27
T ₄ RDF + Soil application of FeSO ₄ @ 10 kg ha ⁻¹	22.67	101.00	9.43	10.80	1.90	35.80
T ₅ RDF + Soil application of borax @ 10 kg ha ⁻¹	22.33	101.67	10.07	11.67	1.97	37.87
T ₆ RDF + Soil application of ZnSO ₄ + FeSO ₄ + borax	22.00	102.67	10.67	12.47	1.90	39.00
T ₇ RDF + Foliar application of ZnSO ₄ @ 0.2%	23.67	100.67	8.63	9.67	1.87	33.11
T ₈ RDF + Foliar application of FeSO ₄ @ 0.5%	23.67	100.33	8.27	9.47	1.87	32.80

T ₉ RDF + Foliar application of borax @ 0.25%	23.33	100.67	8.87	9.87	1.90	33.62
T ₁₀ RDF + Foliar application of ZnSO ₄ + FeSO ₄ + borax	23.67	102.33	8.93	10.60	1.90	35.70
SE±	0.83	3.53	0.49	0.78	0.06	2.01
CD @ 5%	NS	NS	1.46	2.34	NS	5.97
CV (%)	6.3	6.0	9.1	12.8	6.0	9.9

Table 4: Effect of micronutrient application on pod yield, kernel yield, haulm yield, harvest index and shelling percentage of groundnut

Treatments	Pod yield (kg ha ⁻¹)	Kernel yield (kg ha ⁻¹)	Haulm yield (kg ha ⁻¹)	Harvest index (%)	Shelling (%)
T ₁ Control (RDF)	1769	1087	2455	41.89	61.23
T ₂ RDF + FYM @ 10 t ha ⁻¹	2506	1864	3339	42.93	74.48
T ₃ RDF + Soil application of ZnSO ₄ @ 16 kg ha ⁻¹	2228	1614	3002	42.73	73.24
T ₄ RDF + Soil application of FeSO ₄ @ 10 kg ha ⁻¹	2216	1596	2975	42.72	72.42
T ₅ RDF + Soil application of borax @ 10 kg ha ⁻¹	2271	1642	3053	42.78	72.86
T ₆ RDF + Soil application of ZnSO ₄ @ 16 kg ha ⁻¹ + FeSO ₄ @ 10 kg ha ⁻¹ + borax @ 10 kg ha ⁻¹	2393	1763	3191	42.90	73.40
T ₇ RDF + Foliar application of ZnSO ₄ @ 0.2%	2057	1423	2853	42.00	70.02
T ₈ RDF + Foliar application of FeSO ₄ @ 0.5%	1977	1357	2765	41.81	68.95
T ₉ RDF + Foliar application of borax @ 0.25%	2092	1484	2877	42.17	70.93
T ₁₀ RDF + Foliar application of ZnSO ₄ @ 0.2% + FeSO ₄ @ 0.5% + borax @ 0.25%	2190	1548	2973	42.72	71.43
SE±	113.15	104.51	141.80	1.49	2.14
CD @ 5%	336.18	310.52	421.47	NS	6.36
CV (%)	9.0	11.7	8.3	6.1	5.2

Table 5: Effect of micronutrient application on quality parameters of groundnut

Treatments	Protein (%)	Oil content (%)	Oil yield (kg ha ⁻¹)
T ₁ Control (RDF)	17.29	44.33	481.17
T ₂ RDF + FYM @ 10 t ha ⁻¹	24.85	49.77	928.24
T ₃ RDF + Soil application of ZnSO ₄ @ 16 kg ha ⁻¹	22.56	47.87	772.84
T ₄ RDF + Soil application of FeSO ₄ @ 10 kg ha ⁻¹	22.42	47.80	762.89
T ₅ RDF + Soil application of borax @ 10 kg ha ⁻¹	23.18	48.37	794.75
T ₆ RDF + Soil application of ZnSO ₄ @ 16 kg ha ⁻¹ + FeSO ₄ @ 10 kg ha ⁻¹ + borax @ 10 kg ha ⁻¹	23.74	49.37	870.17
T ₇ RDF + Foliar application of ZnSO ₄ @ 0.2%	20.76	45.52	647.75
T ₈ RDF + Foliar application of FeSO ₄ @ 0.5%	19.67	44.91	609.52
T ₉ RDF + Foliar application of borax @ 0.25%	21.18	45.92	681.45
T ₁₀ RDF + Foliar application of ZnSO ₄ @ 0.2% + FeSO ₄ @ 0.5% + borax @ 0.25%	22.09	46.63	721.71
SE±	1.14	1.28	52.67
CD @ 5%	3.38	3.80	156.54
CV (%)	8.6	4.7	12.1

Conclusion

The present study demonstrated that both soil and foliar application of micronutrients improved the growth, yield, and quality of groundnut cultivated in sandy soils; however, the magnitude of response varied with the method of application. Application of FYM @ 10 t ha⁻¹ (T₂) proved to be the most effective treatment, recording the highest growth, yield attributes, pod yield, kernel yield, protein content, oil content, and oil yield. Among the inorganic micronutrient treatments, the combined soil application of ZnSO₄ + FeSO₄ + borax (T₆) consistently outperformed individual soil and foliar applications, indicating the advantage of balanced micronutrient nutrition. Although combined foliar application also improved crop performance over the control, its response was comparatively lower than that of combined soil application. These findings suggest that integrated nutrient management through FYM or, where organic manure is unavailable, combined soil application of Zn, Fe, and B is an effective strategy for improving productivity and quality of groundnut under sandy soil conditions. The study highlights the importance of balanced micronutrient management for sustainable groundnut

cultivation and provides a practical nutrient management option for micronutrient-deficient sandy soils.

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