



Optimization of foliar micronutrient application for enhancing growth, yield and economic returns of potato in Indo-Gangetic plains

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ABSTRACT

Zinc (Zn) and Boron (B) are critical micronutrients that significantly contribute to increased potato yield. Therefore, a field experiment was conducted to evaluate the impact of foliar application of micronutrients on potato growth and yield. Nine treatments {boron (50 and 100 mg L⁻¹), zinc sulphate (150 and 300 mg L⁻¹), their combinations (150+50 and 300+100 mg L⁻¹ of ZnSO₄ and B, respectively) DAP Vegetable Special IIHR (5 g L⁻¹), Potato Specific Nutrients (4 g L⁻¹) and control (water spray)} were laid out in a randomized block design (RBD) with three replications. The foliar spraying of zinc sulphate at 300 mg L⁻¹ + boron at 100 mg L⁻¹ gave the highest values for plant height at 90 DAP (77.5 cm), number of stems per hill and tuber yield per plot (kg plot⁻¹) in the weight categories >75 g (24.0 kg), 50-75 g (16.4 kg), 25-50 g (15.0 kg) and <25 g (5.2 kg). This treatment recorded highest marketable yield (385.0 q ha⁻¹), gross returns (Rs. 2,08,200 ha⁻¹), net returns (Rs. 90,361 ha⁻¹) as well as benefit-cost ratio (1.77). Thus, foliar supplementation of zinc sulphate at 300 mg L⁻¹ in combination with boron at 100 mg L⁻¹, in addition to recommended fertilization, proved most effective in improving productivity and profitability of the potato cultivar *Kufri Bahar*.

Keywords: Potato, Growth, Yield, Micronutrients, Foliar application

INTRODUCTION

Potato (*Solanum tuberosum* L.), a member of the Solanaceae family, is a vital food crop grown extensively across temperate and subtropical regions. It is cultivated in more than 100 countries and ranks among the top five staple crops globally. India holds a prominent position in global potato production, with an output of 57053.34 million tonnes from 2322.23 thousand hectares during 2023-24, making it the second-largest producer after China (Anonymous, 2025). The crop is cultivated in nearly all Indian states except Kerala, with Uttar Pradesh, West Bengal, Punjab, Bihar, Haryana, Madhya Pradesh, Gujarat and Maharashtra being the principal potato-growing regions.

The intensification of agricultural practices has led to overreliance on chemical fertilizers, often with little attention to micronutrient balance. This has resulted in widespread depletion of essential micronutrients such as zinc (Zn), boron (B), iron (Fe), copper (Cu) and manganese (Mn) from Indian soils. Even in intensively cultivated areas where macronutrients are applied adequately, declining yield trends have been reported, largely due to the poor bioavailability of micronutrients. In alkaline and calcareous soils typical of many parts of the Indo-Gangetic plains, the fixation of micronutrients limits their availability to plants, thereby constraining crop productivity.

Potato, owing to its shallow root system and high biomass accumulation over a short growing

period, exhibits high sensitivity to micronutrient deficiencies. Micronutrients, although required in trace amounts, are essential for various physiological and biochemical processes, including enzymatic activity, protein and nucleic acid synthesis, cell division and metabolic regulation (Kohraee *et al.*, 2011). Among these, zinc and boron are particularly significant in improving tuber yield and quality. Zinc plays an important role in enzyme activation, hormone regulation, protein biosynthesis and chlorophyll formation (Kumar *et al.*, 2016). Deficiency of zinc in potato manifests as chlorosis, bronzing of leaves and distortion of growth, which ultimately reduces tuber yield and starch accumulation (Alloway, 2004). Zn deficiency not only hampers yield and quality of plants but also is a major concern for human nutrition (Rani *et al.*, 2024). Boron plays an equally crucial role, particularly in cell wall formation, sugar transport, reproductive development and auxin metabolism. Under micronutrients deficiency, potato plants show symptoms like bushy plant appearance, chlorotic and necrotic foliage, and poor skin quality and structural integrity of tubers (Reisenauer *et al.*, 1973; Ziaeyan and Rajaie, 2009; Naumann *et al.*, 2020).

The method of nutrient application plays a significant role in nutrient use efficiency. Soil-applied micronutrients often exhibit limited mobility and availability due to interactions with soil colloids, especially under alkaline conditions. In contrast, foliar application enables rapid absorption and translocation of nutrients directly through the leaf cuticle, bypassing soil-related constraints. This method has been reported to enhance nutrient use efficiency and improve crop performance under both deficient and marginal conditions (Kinaci and Gulmezoglu, 2007; Babaeian *et al.*, 2011). Additionally, foliar application of micronutrients can augment the effectiveness of macronutrients and contribute positively to crop growth duration, tuber development, and overall yield quality (Narimani *et al.*, 2010; Gabr *et al.*, 2001; Bekhit *et al.*, 2005).

Although the vital roles of zinc and boron in potato nutrition are well documented globally, limited empirical evidence exists under the agro-climatic conditions of the Indo-Gangetic plains. Therefore, the present study was undertaken to investigate the influence of foliar application of micronutrients on the growth, tuber yield and benefit cost ratio of potato in this ecologically and economically significant region.

MATERIALS AND METHODS

Experimental Site

The field experiment was conducted at the Research Farm of the Department of Vegetable Science, CCS Haryana Agricultural University, Hisar, Haryana, India. The experimental site is located at 29°10' N latitude and 75°46' E longitude, with an elevation of 215.2 m above mean sea level. The region experiences a semi-arid climate characterized by an average annual rainfall ranging between 400 and 500 mm. A major portion of the rainfall, approximately 80-90%, is received during the southwest monsoon period extending from July to September. Sporadic rainfall events also occur due to cyclonic disturbances in the months of December, January or during late spring. Rainfall in this region is generally erratic, with considerable inter-annual (20-30%) and seasonal (30-50%) variability. The initial physico-chemical characteristics of the soil at the experimental site prior to potato planting are presented in Table 1.

Experimental Design and Field Treatments

The experiment was laid out in a Randomized Block Design (RBD) to minimize experimental error and enhance the reliability of the results. The gross plot size was maintained at 4.8 × 4.0 m², while the net plot area measured 3.6 × 3.6 m². The foliar application of micronutrients included boron @ of 50 mg l⁻¹ and 100 mg l⁻¹, zinc sulphate (ZnSO₄) @

Table 1. Initial soil properties of the experimental field

Particulars	Content	Method used
pH	8.1	pH meter with glass electrode in 1:2 Soil Water Suspension (Jackson, 1973)
Electrical Conductivity (dS m ⁻¹)	1.03	Conductivity Bridge Method (Richards, 1954)
Organic carbon (%)	0.31	Digestion Method (Walkley and Black, 1934)
Available nitrogen (kg ha ⁻¹)	185	Alkaline Permanganate Method (Subbiah and Asija, 1956)
Available phosphorus (kg ha ⁻¹)	12	Olsen's Method (Olsen <i>et al.</i> , 1954)
Available potassium (kg ha ⁻¹)	268	Flame Photometric Method (Jackson, 1973)

150 mg l⁻¹ and 300 mg l⁻¹, combinations of ZnSO₄, 150 mg l⁻¹ + boron 50 mg l⁻¹ and ZnSO₄ 300 mg l⁻¹ + boron 100 mg l⁻¹, Vegetable Special (IIHR) @ 5 g l⁻¹, and Potato Specific Nutrients @ 4 g l⁻¹ were applied at 30, 45 and 60 days after planting (DAP) along with a water spray used as the control in potato crop.

Sowing Methodology and Crop Management

The experimental field was prepared by performing three successive ploughings, each followed by planking to ensure a fine tilth and uniform soil texture. After the field was adequately prepared, plots of the required dimensions were demarcated according to the treatment layout. Within each plot, planting rows were spaced at 60 cm, marked using a rope for precision. Potato variety 'Kufri Bahar' was planted in the second fortnight of October. Uniform, well-sprouted, healthy seed tubers weighing between 40-50 g were manually placed at 20 cm spacing within ridges. The recommended fertilizer dose of nitrogen, phosphorus and potassium (NPK) at 150:50:100 kg ha⁻¹ was applied through band placement approximately 4-5 cm away from both sides of the planting ridge. Following fertilizer application, soil was heaped from both sides to cover the tubers, forming ridges approximately 15-20 cm in height, ensuring that the tubers remained fully covered and protected from light exposure. All the cultural practices were done according to package of practices of the university.

Data Collection and Recording of Agronomic Parameters

At 90 days after planting, ten plants were randomly selected from each plot to record plant height, which was measured from the base of the shoot to the apex of the terminal leaf using a meter scale and the average was calculated. At final harvest, the fresh weight of leaves per hill was determined by selecting five representative plants from each plot. The leaves from these plants were detached and weighed using a digital balance, and the average weight per hill was expressed in grams. The same plants were then used to determine stem weight per hill by removing all leaves and weighing the stems separately, after which the average was calculated. Foliage weight was recorded at 100 days after planting by harvesting the above-ground biomass (haulm) from the net plot area. The total haulm weight was measured in kilograms and

converted to per square meter basis by dividing with the net plot area and subsequently expressed as quintals per hectare.

The total number of tubers from each net plot was counted and divided by the plot area to determine the tuber count per square meter, which was further extrapolated to calculate the total number of tubers per hectare. After harvest, tubers were sorted into four size grades based on individual tuber weight: Grade A (>75 g), Grade B (50–75 g), Grade C (25–50 g), and Grade D (≤25 g). Each grade was weighed separately, and the sum of A, B and C grades were considered as marketable yield. The marketable and total tuber yields were initially recorded in kilograms per square meter and converted to quintals per hectare. Biological yield, representing the total crop biomass, was obtained by summing the tuber yield and foliage weight per plot and expressing the value in quintals per hectare. Harvest index was computed as the ratio of economic yield (tuber yield) to biological yield and expressed as a percentage using the formula:

$$\text{Harvest Index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

For determining dry matter accumulation, representative fresh tuber samples from each treatment were cut into small pieces and initially sun-dried for 2–3 days under polyhouse conditions, followed by oven drying at 70°C until a constant weight was achieved. Dry matter content was then calculated as a percentage using the formula:

$$\text{Dry weight of tuber (\%)} = \frac{\text{Dry weight of tuber}}{\text{Fresh weight of tuber}} \times 100$$

Gross returns were Computed by multiplying the marketable tuber yield per hectare by the average market price of potatoes (Rs./q). Net Returns were obtained by subtracting the total cost of cultivation from the gross return for each treatment. Benefit-cost Ratio was calculated using the formula:

$$\text{B: C} = \frac{\text{Gross returns (Rs./ha)}}{\text{Cost of cultivation (Rs./ha)}}$$

Statistical Analysis

The experimental data were statistically analyzed using the standard procedure for Randomized Block Design (RBD). Analysis of variance (ANOVA) was performed to determine the significance of treatment effects on the recorded parameters. The significance of the differences

Table 2. Effect of foliar application of micronutrients on growth parameters and no. of tubers in potato cv. *Kufri Bahar*

Treatments	Plant height (cm) at 90 DAP	No. of stems/hill	Leaf weight (g hill ⁻¹)	Stem weight (g hill ⁻¹)	Weight of foliage (q/ha)	Total no. of tuber/ ha
Boron 50 mg/l	70.2	4.2	151.3	97.1	179.7	629861
Boron 100 mg/l	72.1	4.4	154.5	97.9	184.8	638657
ZnSO ₄ 150 mg/l	73.1	4.6	156.3	100.5	186.9	654398
ZnSO ₄ 300 mg/l	73.6	4.8	168.7	103.3	191.8	666898
ZnSO ₄ 150 mg/l + Boron 50 mg/l	74.3	5.0	180.5	108.7	196.8	679630
ZnSO ₄ 300 mg/l + Boron 100 mg/l	77.5	5.4	190.3	111.3	204.9	685417
Vegetable Special IIHR 5 g/l	71.1	4.7	175.6	105.5	194.4	662153
Potato Specific Nutrients 4 g/l	72.8	4.8	178.2	106.2	195.3	662731
Control (water spray)	68.8	4.1	150.3	96.7	176.2	621991
C.D. at 5%	3.2	0.7	68.8	2.6	9.4	10434

among treatment means was tested at 5% probability level ($P < 0.05$) using the least significant difference (LSD) test. The statistical computations were carried out using OPSTAT software developed by CCS Haryana Agricultural University, Hisar, India (Sheoran, 2010).

RESULTS AND DISCUSSION

Effect on Growth Parameters and Number of Tubers

The growth attributes of potato responded significantly to foliar application of micronutrients, with marked improvements observed in leaf and stem biomass across the treated plots (Table 2). Among all treatment combinations, the application of zinc sulphate at 300 mg L⁻¹ along with boron at 100 mg L⁻¹ resulted in the highest leaf weight per hill (190.3 g), followed by the combination of zinc sulphate at 150 mg L⁻¹ and boron at 50 mg L⁻¹ (180.5 g hill⁻¹). In contrast, the untreated control exhibited the lowest leaf biomass (150.3 g hill⁻¹), indicating the importance of micronutrients in enhancing vegetative growth. A similar response pattern was recorded in stem biomass. The highest stem weight (111.3 g hill⁻¹) was achieved with the highest dose of zinc and boron applied together, followed with the lower combined dose. The minimum stem weight (96.7 g hill⁻¹) was recorded in the control treatment, clearly suggesting a synergistic effect of zinc and boron on shoot development.

The improvement in individual growth components translated into increased total foliage production. The combined foliar application of zinc sulphate (300 mg L⁻¹) and boron (100 mg L⁻¹) produced the highest foliage biomass, recording 2.28 kg m⁻² on an area basis and 204.9 q ha⁻¹ on a yield

basis which was followed by the lower combination dose (Zinc 150 mg L⁻¹ + 50 mg L⁻¹) resulted in 2.19 kg m⁻² and 196.8 q ha⁻¹, respectively. Notably, the control plot recorded the lowest foliage biomass (1.96 kg m⁻² and 176.2 q ha⁻¹) suggesting that micronutrient deficiency limited vegetative growth under untreated conditions.

These improvements in vegetative growth were accompanied by a corresponding increase in tuber number. The highest number of tubers per hectare (6,85,417) was recorded in the treatment receiving 300 mg L⁻¹ zinc sulphate and 100 mg L⁻¹ boron, followed closely by 6,79,630 tubers ha⁻¹ under the lower combined dose (Zinc 150 mg L⁻¹ + 50 mg L⁻¹). In contrast, the control treatment recorded the lowest tuber count (6,21,991 ha⁻¹), reflecting the cumulative impact of enhanced leaf and stem biomass on the sink capacity of the crop (Table 2). Overall, the results clearly demonstrate that foliar application of zinc and boron, particularly in combination, exerts a beneficial effect on the vegetative growth and productivity of potato. The positive influence on foliage development is likely to have contributed to improved photosynthetic capacity, which in turn supported greater tuber initiation and development (Table 2).

Foliar application of zinc and boron markedly improved growth, biomass accumulation, and tuber yield in potato. Among all treatments, the combination of zinc sulphate (300 mg L⁻¹) and boron (100 mg L⁻¹) applied at 30, 45 and 60 days after planting consistently outperformed others in key growth and yield parameters as well as economically. Enhanced vegetative traits such as plant height, number of stems per hill and foliage biomass under this treatment can be attributed to the synergistic roles of zinc and boron in regulating physiological

and metabolic processes. Zinc is known to influence auxin synthesis, enzymatic activation, and protein metabolism, while boron is critical for cell wall integrity, sugar translocation, and meristematic activity (Mengel and Kirkby 2001; Trehan and Grewal 1981). The observed increase in stem proliferation and vegetative mass aligns with earlier reports in potato (Ahmed *et al.* 2015; Kumar *et al.* 2017; Ahmed *et al.* 2011).

The foliar application of micronutrients significantly increases in leaf and stem biomass, as well as overall foliage yield per hectare, enhanced photosynthetic efficiency and assimilate production with. These outcomes are consistent with the findings of Barman *et al.* (2018), Rahman *et al.* (2011) and Taheri *et al.* (2012), who reported improved canopy growth under micronutrient supplementation.

Effect on Tuber Yield of Different Grades

Grading of tubers based on weight revealed a significant influence of foliar-applied micronutrients on the marketable categories, while no notable effect was observed on the yield of the smallest grade (Table 3). The highest yields of A-grade tubers (>75 g), B-grade (50–75 g) and C-grade (25–50 g) were obtained in the treatment involving the combined foliar application of zinc sulphate at 300 mg L⁻¹ and boron at 100 mg L⁻¹. This treatment produced 24.02 kg plot⁻¹ of A-grade, 16.43 kg plot⁻¹ of B-grade and 15.00 kg plot⁻¹ of C-grade tubers, which were significantly superior to most other treatments. The next best performance was observed with the lower combined dose of zinc sulphate (150 mg L⁻¹) and boron (50 mg L⁻¹), which also resulted in appreciably higher yields across all major grades, though

marginally lower than the highest dose. In contrast, the untreated control consistently recorded the lowest marketable tuber (A, B and C-grade categories) marketable tuber production under micronutrient-deficient conditions.

The yield of D-grade tubers (≤25 g) did not differ significantly among treatments, suggesting that foliar application of micronutrients primarily enhanced the size and weight distribution of tubers rather than increasing the proportion of undersized ones. The absence of significant variation in the smallest grade implies that the observed improvements in higher-grade yields were more likely due to enhanced nutrient utilization and better translocation of assimilates, rather than an increase in total tuber number alone. These results emphasize the role of balanced micronutrient nutrition, particularly through foliar supplementation of zinc and boron, in shifting the yield distribution towards higher-grade tubers, thereby contributing to improved marketable yield and potential economic returns.

The treatment also significantly increased the marketable yield of A, B, and C grade tubers, reflecting superior assimilate partitioning and efficient source - sink dynamics. The promotion of larger tuber grades under micronutrient sprays likely resulted from improved photosynthate transport and cellular development, supported by the roles of zinc in auxin-mediated growth and boron in carbohydrate movement and reproductive development (Parmar *et al.*, 2016; Thakare *et al.*, 2007).

Effect on Yield, Harvest Index and Percent Dry Weight of Tuber

The yield of potato was significantly influenced by the foliar application of zinc and boron, either

Table 3. Effect of foliar application of micronutrients on number of different grade tubers per plot at harvest in potato cv. Kufri Bahar

Treatments	Number of tubers per plot			
	A- grade (> 75 g)	B- grade (50-75 g)	(25-50 g) C- grade	D- grade (upto 25 g)
Boron 50 mg/l	132.3	195.3	267.0	312.3
Boron 100 mg/l	137.0	198.0	273.3	311.3
ZnSO ₄ 150 mg/l	147.3	203.3	279.7	312.0
ZnSO ₄ 300 mg/l	150.3	208.7	285.3	316.0
ZnSO ₄ 150 mg/l + Boron 50 mg/l	159.0	218.7	289.3	311.7
ZnSO ₄ 300 mg/l + Boron 100 mg/l	168.0	228.0	294.3	296.7
Vegetable Special IIHR 5 g/l	149.5	206.3	283.0	314.7
Potato Specific Nutrients 4 g/l	157.7	212.0	284.7	300.0
Control (water spray)	130.7	194.0	252.7	318.3
C.D. at 5%	9.8	11.6	8.8	NS

Table 4. Effect of foliar application of micronutrients on marketable and total tuber yield (q ha⁻¹) in potato cv. *Kufri Bahar*

Treatments	Total yield perplot (kg)	Total yield (q/ha)	Marketable yield (q/ha)
Boron 50 mg/l	52.80	366.7	324.7
Boron 100 mg/l	53.78	373.4	331.2
ZnSO ₄ 150 mg/l	55.19	383.3	342.7
ZnSO ₄ 300 mg/l	57.36	398.3	359.2
ZnSO ₄ 150 mg/l + Boron 50 mg/l	58.86	408.7	372.5
ZnSO ₄ 300 mg/l + Boron 100 mg/l	59.96	416.4	385.0
Vegetable Special IIHR 5 g/l	55.81	387.6	352.4
Potato Specific Nutrients 4 g/l	56.99	395.8	361.3
Control (water spray)	52.48	364.4	322.0
C.D. at 5%	2.49	16.1	14.5

alone or in combination. Marketable yield showed notable variation across treatments, with the highest yield (385.0 q ha⁻¹) recorded under the foliar application of zinc sulphate at 300 mg L⁻¹ combined with boron at 100 mg L⁻¹ (Table 4). Followed by lower combined dose (zinc sulphate 150 mg L⁻¹ + boron 50 mg L⁻¹), which produced 372.5 q ha⁻¹ tuber yield. The control treatment, where no micronutrient was applied, recorded the lowest marketable yield (322.0 q ha⁻¹), reflecting the limited nutrient availability in the absence of supplementation.

Biological yield, which represents the total above-ground biomass including tubers, also responded positively to micronutrient application. The highest biological yield (621.3 q ha⁻¹) was achieved with the foliar application of zinc sulphate at 300 mg L⁻¹ and boron at 100 mg L⁻¹, significantly outperforming most other treatments (Table 5) which was closely followed by the lower combination dose (150 mg L⁻¹ zinc sulphate + 50 mg L⁻¹ boron), recorded 605.5 q ha⁻¹ a biological yield of. The control plot, where only water was sprayed, recorded the lowest biological yield (540.6 q ha⁻¹), suggesting

that the absence of micronutrient input constrained overall biomass accumulation. In contrast to yield parameters, the harvest index did not show significant variation across treatments (66.6 to 67.5%) indicating that total biomass and marketable tuber yield increased with micronutrient application, the proportional allocation of assimilates to tubers remained relatively stable.

The percent dry weight of tubers, an important indicator of quality and storage potential, was significantly influenced by the foliar application of micronutrients (Table 5). The highest dry matter content (17.38%) was recorded in the treatment receiving zinc sulphate at 300 mg L⁻¹ and boron at 100 mg L⁻¹, which was statistically at par with the 150 mg L⁻¹ zinc + 50 mg L⁻¹ boron combination (17.28%). The control treatment recorded the lowest dry matter content (16.03%), highlighting the positive role of micronutrient foliar sprays in improving tuber quality through enhanced carbohydrate accumulation. Overall, these results suggest that foliar application of zinc and boron, particularly in combination, not only enhances yield

Table 5. Effect of foliar application of micronutrients on biological yield, harvest index and percent dry weight of tuber in potato cv. *Kufri Bahar*

Treatments	Biological yield (q ha ⁻¹)	Harvest index	Percent dry weight of tuber
Boron 50 mg/l	546.4	67.1	16.05
Boron 100 mg/l	558.3	66.9	16.17
ZnSO ₄ 150 mg/l	570.2	67.2	16.34
ZnSO ₄ 300 mg/l	590.1	67.5	16.81
ZnSO ₄ 150 mg/l + Boron 50 mg/l	605.5	67.5	17.28
ZnSO ₄ 300 mg/l + Boron 100 mg/l	621.3	67.0	17.38
Vegetable Special IIHR 5 g/l	582.0	66.6	16.50
Potato Specific Nutrients 4 g/l	591.1	67.0	16.74
Control (water spray)	540.6	67.4	16.03
C.D. at 5%	18.6	N.S.	0.52

Table 6. Effect of foliar application of micronutrients on economics of various treatments in potato cv. *Kufri Bahar*

Treatments	Common cost (Rs. ha ⁻¹)	Treatment cost (Rs. ha ⁻¹)	Total cost (Rs. ha ⁻¹)	Gross return (Rs. ha ⁻¹)	Net return (Rs. ha ⁻¹)	B:C
Boron 50 mg/l	114815	672	115487	183350	67863	1.59
Boron 100 mg/l	114815	1344	116159	186700	70541	1.61
ZnSO ₄ 150 mg/l	114815	840	115655	191650	75995	1.66
ZnSO ₄ 300 mg/l	114815	1680	116495	199150	82655	1.71
ZnSO ₄ 150 mg/l + Boron 50 mg/l	114815	1512	116327	204350	88023	1.76
ZnSO ₄ 300 mg/l + Boron 100 mg/l	114815	3024	117839	208200	90361	1.77
Vegetable Special IHR 5 g/l	114815	1706	116521	193800	77279	1.66
Potato Specific Nutrients 4 g/l	114815	1365	116180	197900	81720	1.70
Control (water spray)	114815	200	115015	182200	67185	1.58

potential but also improves tuber dry matter content without affecting the harvest index. The enhanced biological and marketable yield, together with improved tuber quality, underscores the importance of balanced micronutrient management in potato cultivation under the agro-climatic conditions of the Indo-Gangetic plains.

Biological yield and dry matter content was recorded maximum with the same level of micronutrient application (300 mg ZnSO₄ and 100 mg B) which may be linked to better foliage productivity, enhanced carbohydrate accumulation and optimized physiological function. Harvest index was not significantly affected by the application of micronutrient. The increased dry matter suggests efficient carbon assimilation and mobilization toward sink tissues, as corroborated by Singh *et al.* (2018), Singh and Kushwah (2006), Mohapatra *et al.* (2008) and Narayan *et al.* (2014).

Economic Analysis

The cost of potato cultivation varied from 1,15,015 to 1,17,839 ha⁻¹ depending on the micronutrient doses (Table 6). The lowest cost was recorded in control (water spray only), while the highest was incurred in the treatment receiving zinc sulphate at 300 mg L⁻¹ combined with boron at 100 mg L⁻¹. Gross and net returns reflected yield performance across treatments. The highest gross return (₹ 2,08,200 ha⁻¹) and net return (₹ 90,361 ha⁻¹) were obtained with the combined foliar application of 300 mg L⁻¹ zinc and 100 mg L⁻¹ boron, followed by the lower combination dose (150 mg L⁻¹ zinc + 50 mg L⁻¹ boron). In contrast, the control treatment yielded the lowest gross (₹ 1,82,200 ha⁻¹) and net returns (₹ 67,185 ha⁻¹). The benefit-cost ratio was maximized (1.77) under the highest micronutrient dose, with the lower combination treatment showing

a comparable value (1.76). The control recorded the lowest B:C (1.58). These results indicate that foliar application of zinc and boron, particularly at higher doses, enhances both productivity and profitability in potato cultivation. These results were found to be accorded with Amarananjundeswara *et al.* (2020).

CONCLUSION

The present study demonstrated that foliar application of zinc sulphate in combination with boron markedly enhanced growth, yield and quality parameters of potato under field conditions. Among all treatments, foliar application of zinc sulphate (300 mg L⁻¹) combined with boron (100 mg L⁻¹) applied at 30, 45 and 60 DAP resulted in the highest plant height, marketable tuber count, total yield, dry matter content and economic returns. The combined application of zinc and boron outperformed their individual effects, highlighting a synergistic influence on tuber development. Overall, the integrated use of zinc and boron through foliar application in appropriate concentrations significantly enhanced both vegetative and reproductive traits in potato. These findings underscore the importance of balanced micronutrient management in improving tuber quality and productivity under field conditions. Thus, foliar application of zinc sulphate (300 mg L⁻¹) combined with boron (100 mg L⁻¹), in addition to the recommended fertilizer dose, can be recommended as an effective strategy to improve productivity and profitability of potato (cv. *Kufri Bahar*) in the Indo-Gangetic plains.

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CONFLICT OF INTEREST

The authors have not any conflict of interest.

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