



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(6): 889-893
Received: 02-03-2026
Accepted: 08-04-2026

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Effect of foliar application of boron, zinc and manganese on vegetative growth of Potato (*Solanum tuberosum* L. c.v Kufri lima)

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i6l.5799>

Abstract

A field investigation was carried out during the Rabi season of 2025-2026 at the Centre of Excellence for Vegetable Science, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, to evaluate the impact of foliar-applied micronutrients specifically Boron (B), Zinc (Zn), and Manganese (Mn) on the vegetative growth parameters of potato (*Solanum tuberosum* L. cv. Kufri Lima). The field study was executed using a Randomized Block Design with eight explicit treatments replicated thrice. The treatments included T₈: (Boron 2.0 g + Zinc 1.0 g + Manganese 2.0 g). recorded the highest value of all the growth parameters. The plots deliver with this treatment demonstrated maximum plant height (25.53 cm, 56.23 cm, 70.63 cm at 30, 60 and 90 DAP) leaf number per plant (11.67, 20.0, 25.33 at 30, 60 and 90 DAP) expanded leaf length (4.83, 6.60, 8.10 at 30, 60 and 90 DAP), primary stem diameter (4.87 cm, 5.03 cm, 5.23 cm). These findings indicate that the combined application of micronutrients Boron + Zinc + Manganese can substantially enhance growth of potato on the field.

Keywords: Potato, *Solanum tuberosum*, Kufri lima, zinc, manganese, boron vegetative ontogeny

Introduction

The potato (*Solanum tuberosum* L.) constitutes a fundamental pillar of global food security, positioned as the third most significant food crop globally, following rice and wheat. Cultivated in over 150 nations across various agro-ecological contexts, this crop demonstrates an exceptional ability to yield high caloric output per unit area and enhance water use efficiency in comparison to predominant cereal crops. Originating from the vicinity of Lake Titicaca in the elevated Andes region around 6000 BC, this Solanaceous species flourishes optimally within a thermal range of 18-20 °C. Its comprehensive nutritional composition, abundant in essential carbohydrates, potassium, ascorbic acid, dietary fibre, bioavailable iron, and crucial B-complex vitamins, renders it vital for combating malnutrition and economic susceptibility in developing areas of South Asia, South America, and Africa.

Within the Indian agricultural framework, the Indo-Gangetic alluvial plains of Uttar Pradesh are recognized as a principal region for potato cultivation, accounting for approximately 35% of the national output. Nevertheless, the sustainability and productivity of intensive cropping systems, such as the widely implemented maize-potato-mung bean rotation, are increasingly undermined by the multi-nutrient depletion within the soil profile. While the management of macronutrients (Nitrogen, Phosphorus, Potassium) has garnered considerable focus, the concurrent depletion of essential trace elements or micronutrients continues to pose a significant limitation. Micronutrients, although required in minuscule amounts, serve as catalytic agents in regulating primary plant metabolic processes, facilitating structural cell wall formation, activating enzyme cascades, directing electron transport pathways, and fortifying defences against abiotic stress. Notably, Zinc (Zn), Boron (B), and Manganese (Mn) exhibit pronounced and pervasive deficiencies in the alluvial soils of northern India, constraining the structural development and canopy expression of cultivars such as cv. Kufri Lima.

Foliar feeding has surfaced as a methodologically effective and expeditious diagnostic strategy to

rectify these deficiencies. In contrast to conventional soil amendments, which are often subjected to significant nutrient immobilization, precipitation, or leaching under alkaline soil conditions (characterized by high pH and calcium carbonate accumulation), foliar sprays facilitate the direct application of dissolved nutrients onto the active canopy. The essential nutrients penetrate through the leaf cuticle and stomatal apertures, entering the metabolic sinks with immediacy. This focused approach guarantees swift biochemical assimilation, thereby optimizing vegetative parameters during critical structural phases such as the initial stolon formation and the development of vegetative branches.

Physiological Functionality of Zinc (Zn)

Zinc functions as an essential catalytic and structural element in more than 300 plant enzymes and signaling proteins. It serves as a principal regulator of tryptophan biosynthesis, which is the crucial amino acid precursor for Indole-Acetic Acid (IAA), the predominant auxin that facilitates cellular elongation, apical dominance, and the elongation of structural nodes. Furthermore, zinc is indispensable for the assembly of proteins, the replication of RNA and DNA, the stability of chlorophyll, and the process of carbon fixation mediated by carbonic anhydrase. In instances of severe zinc deficiency, potato plants demonstrate typical morphological aberrations such as pronounced internodal compression, resetting, significant leaf chlorosis, and structural stunting, which constrains overall light interception.

Structural Functionality of Boron (B)

Boron serves primarily as a pivotal structural element within the cell wall matrix, facilitating the cross-linking of pectic polysaccharides (notably rhamnogalacturonan II) to confer mechanical stability and modulate elasticity during phases of active growth. It is indispensable for maintaining the structural integrity of plasma membranes, facilitating cellular division within apical meristems, and enabling the phloem-mediated translocation of sucrose from foliar sources to vegetative sinks. Given that boron exhibits minimal phloem mobility in the majority of higher plants, any disruption in its external supply precipitates rapid functional failure in apical growing points, culminating in apical necrosis, a loss of apical dominance, and a compromise in the mechanical robustness of petiole and stem structures.

Catalytic Functionality of Manganese (Mn)

Manganese functions as a vital element within the oxygen-evolving complex (OEC) of Photosystem II, facilitating the photolytic dissociation of water molecules that supply electrons essential for the photosynthetic electron transport chain. It serves as an obligatory activator for critical metabolic enzymes, encompassing those regulating nitrogen assimilation (nitrate reductase), fatty acid biosynthesis, and the phenylpropanoid pathway, which is integral to the biosynthesis of lignin and structural flavonoids. A deficiency in manganese elicits 'speckled yellows' chlorosis, interveinal structural deterioration, and the emergence of localized necrotic lesions, leading to a reduction in total leaf area and a consequent impairment in photosynthetic efficiency.

Materials and Methods

Experimental Sites and Location

The field experiment was executed during the Rabi season of 2025-2026 at Plot Number 13 of the Research Field located at the Centre of Excellence for Vegetable Science, Chandra Shekhar

Azad University of Agriculture & Technology, Kanpur, India (26.46° N, 80.33° E). The site is characterized by a typical sub-humid, subtropical climate, featuring hot, arid summers and cool winters. Weekly meteorological observations throughout the active crop cycle recorded mean maximum temperatures varying from 15.2 °C to 32.4 °C, while minimum temperatures oscillated between 2.0 °C and 10.5 °C. The relative humidity at 07:00 AM consistently remained elevated at levels between 95% and 97%, whereas the afternoon relative humidity (at 02:00 PM) fluctuated between 30% and 64%. The historical cropping sequence over the previous three seasons adhered to a consistent maize-potato-mung bean rotation, thereby ensuring uniform baseline management of structural conditions across the experimental plot area.

Experimental Architecture and Treatments Setup

The experimental design was structured as a Randomized Block Design (RBD) comprising eight distinct treatments, each replicated three times across 24 plots measuring 3.0 m × 2.4 m. The certified potato cultivar 'Kufri Lima' was sown on November 19, 2025, employing a uniform spacing of 60 cm between rows and 20 cm between individual plants. Healthy and uniform seed tubers (ranging from 35-40 mm in diameter and weighing 45-50 g) were subjected to treatment with a 0.2% Mancozeb solution for a duration of 10 minutes to mitigate the risk of soil-borne pathogens prior to planting. The experimental plots received a uniform basal fertilizer application of N:P: K at 150:90:100 kg ha⁻¹. Nitrogen was managed as a split application, with half applied basally and the remaining half top-dressed during the first earthing-up operation at 45 days after planting.

Treatment Code	Micronutrient Formulation / Combination Details	Application Concentration per Litre of Water
T ₁	Absolute Control (No micronutrient spray)	Deionized Water Spray only
T ₂	Boron (B) singular foliar spray	2.0 grams of Borax [Na ₂ B ₄ O ₇ ·10H ₂ O]
T ₃	Zinc (Zn) singular foliar spray	1.0 gram of Zinc Sulphate Monohydrate [ZnSO ₄ ·H ₂ O]
T ₄	Manganese (Mn) singular foliar spray	2.0 grams of Manganese Sulphate [MnSO ₄ ·H ₂ O]
T ₅	Boron + Zinc binary combination spray	2.0 g Borax + 1.0 g Zinc Sulphate
T ₆	Boron + Manganese binary combination spray	2.0 g Borax + 2.0 g Manganese Sulphate
T ₇	Zinc + Manganese binary combination spray	1.0 g Zinc Sulphate + 2.0 g Manganese Sulphate
T ₈	Combined Tri-elemental micronutrient spray	2.0 g Borax + 1.0 g Zinc Sulphate + 2.0 g Manganese Sulphate

Execution of Foliar Spray Schedules

The foliar interventions were meticulously administered at 30, 50, and 70 days post-planting (DAP) utilizing a calibrated hand-operated sprayer fitted with a high-efficiency spray lance. This configuration guaranteed consistent canopy coverage while mitigating the potential for draft drift affecting neighboring experimental plots. To avert leaf scorching and optimize stomatal absorption, applications were conducted exclusively during the early morning hours (07:30 AM to 09:30 AM) when wind velocities were minimal and relative humidity levels were deemed optimal. Stock solutions were freshly formulated by dissolving pure analytical-grade mineral salts directly in deionized water, employing suitable personal protective equipment to uphold experimental safety and precision standards.

Results and Discussion

The statistical examination of the vegetative growth parameters indicated that foliar micronutrient applications profoundly altered the structural architecture of potato cultivar Kufri Lima throughout active growth phases. The specific vegetative observations are elucidated below.

Response of Plant Height (cm) to Micronutrient Interventions

Table 1 and Figure 1 present empirical data elucidating the Effect of Foliar Application of Boron, Zinc and Manganese on plant height at 30 days after planting (DAP), it was observed that the application of T₈: (Boron 2.0 g + Zinc 1.0 g + Manganese 2.0 g) at (27.17 cm). In contrast, T₁ Control exhibited the lowest plant height (23.43 cm). The analysis of variance substantiated that treatment discrepancies were statistically non-significant (NS) at

this nascent stage, signifying a lag phase in nutrient absorption and structural assimilation. Upon reaching at (60 DAP), plant height measurements varied from (56.23 cm) and in the control (T₁) to (41.93 cm) At the terminal vegetative maturity stage (90 DAP), the tri-elemental combination T₈ achieved the maximum plant height of (70.63 cm). The control plot (T₁) recorded the minimal plant height of 43.93 cm at 90 DAP. The enhanced plant height observed under T₈ (Boron 2.0 g + Zinc 1.0 g + Manganese 2.0 g) at 60 and 90 DAP indicates the synergistic effect of micronutrients in promoting cell division, elongation, and overall vegetative growth. The non-significant differences at 30 DAP suggest a delayed response to foliar-applied nutrients, whereas significant improvement at later growth stages reflects increased nutrient uptake and utilization by the plants.

Treatment Code	Description of Foliar Treatment	Plant Height at 30 DAP	Plant Height at 60 DAP	Plant Height at 90 DAP
T ₁	Absolute Control (Water Spray)	23.43	41.93	43.93
T ₂	Boron (B) @ 2.0 g/L	24.93	48.47	55.53
T ₃	Zinc (Zn) @ 1.0 g/L	24.90	46.40	52.87
T ₄	Manganese (Mn) @ 2.0 g/L	27.87	46.00	51.27
T ₅	Boron + Zinc (2.0g + 1.0g/L)	26.43	55.40	69.23
T ₆	Boron + Manganese (2.0g + 2.0g/L)	25.53	55.23	67.23
T ₇	Zinc + Manganese (1.0g + 2.0g/L)	25.27	40.43	55.77
T ₈	Boron + Zinc + Manganese	27.17	56.23	70.63
-	Standard Error of Mean (SEm±)	0.80	0.59	0.68
-	Critical Difference (CD at 5%)	NS	1.81	2.09

Canopy Modification: Leaves Count per Plant

Table 2 present empirical data elucidating the Effect of Foliar Application of Boron, Zinc and Manganese on Leaves Count per Plant at 30 days after planting (DAP), it was observed that the application of T₈: (Boron 2.0 g + Zinc 1.0 g + Manganese 2.0 g) at (11.67). In contrast, T₁ Control exhibited the lowest leaf count (9.0). The analysis of variance substantiated that treatment discrepancies were statistically non-significant (NS) at this nascent stage, signifying a lag phase in nutrient absorption and structural assimilation.) Upon reaching at (60 DAP), Leaves Count per Plant measurements varied from (21.0) and in the control (T₁) to (13.33) At the terminal vegetative maturity stage

(90 DAP), the tri-elemental combination T₈ achieved the maximum of (25.33). The control plot (T₁) recorded the minimal Leaves Count per Plant of (15.33) at 90 DAP reflecting limited canopy development under trace element deficiencies. The maximum leaf count recorded under T₈ (Boron 2.0 g + Zinc 1.0 g + Manganese 2.0 g) at 60 and 90 DAP indicates the positive synergistic effect of micronutrients on leaf initiation, expansion, and canopy development. The non-significant variation at 30 DAP suggests delayed nutrient assimilation, while the lower leaf count in the control treatment reflects restricted vegetative growth due to micronutrient deficiency.

Treatment Code	Description of Foliar Treatment	Leaf Count at 30 DAP	Leaf Count at 60 DAP	Leaf Count at 90 DAP
T ₁	Absolute Control (Water Spray)	9.00	13.33	15.33
T ₂	Boron (B) @ 2.0 g/L	10.00	16.33	18.67
T ₃	Zinc (Zn) @ 1.0 g/L	9.67	16.33	18.33
T ₄	Manganese (Mn) @ 2.0 g/L	9.00	16.00	18.00
T ₅	Boron + Zinc (2.0g + 1.0g/L)	11.33	20.00	25.00
T ₆	Boron + Manganese (2.0g + 2.0g/L)	11.00	19.67	23.00
T ₇	Zinc + Manganese (1.0g + 2.0g/L)	10.33	17.00	19.00
T ₈	Boron + Zinc + Manganese	11.67	21.00	25.33
-	Standard Error of Mean (SEm±)	0.69	0.83	0.99
-	Critical Difference (CD at 5%)	NS	2.54	3.04

Leaf Length (cm) Response to Trace Elements

Table 3 present empirical data elucidating the Effect of Foliar Application of Boron, Zinc and Manganese on Leaf length at 30 days after planting (DAP), it was observed that the application of T₈: (Boron 2.0 g + Zinc 1.0 g + Manganese 2.0 g) at (4.83 cm). In contrast, T₁ Control exhibited the lowest Leaf length (4.53 cm). The analysis of variance substantiated that treatment discrepancies were statistically non-significant (NS) at this nascent stage, signifying a lag phase in nutrient absorption and structural assimilation.) Upon reaching at (60 DAP), Leaf length measurements varied from (7.60 cm) and in the control (T₁) to (4.73 cm) At the terminal vegetative maturity stage (90 DAP), the

tri-elemental combination T₈ achieved the maximum Leaf length of (8.10 cm) The control plot (T₁) recorded the minimal Leaf length of (4.97 cm) at 90 DAP reflecting limited canopy development under trace element deficiencies. The significantly greater leaf length observed under T₈ (Boron 2.0 g + Zinc 1.0 g + Manganese 2.0 g) at 60 and 90 DAP suggests that the combined application of micronutrients enhanced cell elongation, photosynthetic surface area, and overall vegetative growth. The non-significant differences at 30 DAP indicate a delayed response to foliar nutrient application, while the reduced leaf length in the control treatment reflects the adverse effects of micronutrient deficiency on leaf development.

Treatment Code	Description of Foliar Treatment	Leaf Length at 30 DAP	Leaf Length at 60 DAP	Leaf Length at 90 DAP
T ₁	Absolute Control (Water Spray)	4.53	4.73	4.97
T ₂	Boron (B) @ 2.0 g/L	4.73	5.23	5.97
T ₃	Zinc (Zn) @ 1.0 g/L	4.70	5.20	5.53
T ₄	Manganese (Mn) @ 2.0 g/L	4.63	4.80	5.40
T ₅	Boron + Zinc (2.0g + 1.0g/L)	4.77	6.50	8.00
T ₆	Boron + Manganese (2.0g + 2.0g/L)	4.73	6.20	7.70
T ₇	Zinc + Manganese (1.0g + 2.0g/L)	4.73	5.87	6.50
T ₈	Boron + Zinc + Manganese	4.83	6.60	8.10
-	Standard Error of Mean (SEM±)	0.10	0.03	0.08
-	Critical Difference (CD at 5%)	NS	0.11	0.24

Primary Stem Diameter (cm) Structural Kinetics

Stem diameter functions as a critical indicator of structural integrity and the capacity for vascular transport. Significant treatment differences were observed across all growth stages, including at 30 DAP. At this stage, the tri-elemental formulation T₈ exhibited the highest stem diameter of 4.87 cm, in contrast, T₁ Control exhibited the lowest primary stem diameter (2.47 cm). This trend persisted at 60 DAP, with T₈ achieving a diameter of (5.03 cm), and T₁ Control exhibited the lowest primary stem diameter (2.93 cm). At the stage of vegetative maturity (90 DAP),

the maximum stem diameter reached 5.23 cm, under in contrast, T₁ Control exhibited the lowest primary stem diameter (T₁: 3.57 cm). The greater stem diameter recorded under T₈ (Boron 2.0 g + Zinc 1.0 g + Manganese 2.0 g) throughout the crop growth period indicates the beneficial role of micronutrients in enhancing cell division, vascular development, and stem strengthening. The consistently lower stem diameter in the control treatment highlights the importance of adequate boron, zinc, and manganese supply for maintaining structural integrity and efficient nutrient translocation.

Treatment Code	Description of Foliar Treatment	Stem Diameter at 30 DAP	Stem Diameter at 60 DAP	Stem Diameter at 90 DAP
T ₁	Absolute Control (Water Spray)	2.47	2.93	3.57
T ₂	Boron (B) @ 2.0 g/L	3.67	3.80	4.00
T ₃	Zinc (Zn) @ 1.0 g/L	3.20	3.47	3.67
T ₄	Manganese (Mn) @ 2.0 g/L	2.87	3.37	3.60
T ₅	Boron + Zinc (2.0g + 1.0g/L)	4.77	4.97	5.17
T ₆	Boron + Manganese (2.0g + 2.0g/L)	4.60	4.80	5.00
T ₇	Zinc + Manganese (1.0g + 2.0g/L)	3.80	3.90	4.10
T ₈	Boron + Zinc + Manganese	4.87	5.03	5.23
-	Standard Error of Mean (SEM±)	0.06	0.06	0.06
-	Critical Difference (CD at 5%)	0.20	0.20	0.19

Summary and Conclusion

The foliar application of boron, zinc, and manganese significantly improved plant growth parameters, including plant height, leaf count, leaf length, and stem diameter. Among all treatments, T₈ (Boron 2.0 g + Zinc 1.0 g + Manganese 2.0 g) consistently recorded the highest values at 60 and 90 DAP. The combined micronutrient application enhanced vegetative growth through improved cell division, elongation, and nutrient translocation. Non-significant differences at 30 DAP indicated delayed nutrient assimilation after foliar application. Overall, T₈ proved to be the most effective treatment for promoting vigorous growth and structural development of the crop.

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