Himachal Journal of Agricultural Research
Volume 52, Issue 1, June 2026; pp. 76–84; DOI: 10.18311/HJAR/2026/36124

INFORMATICS JOURNALS
Crop Production

Soil and Foliar Mediated B Fertilisation Augments Maize Performance, Profitability and Use Efficiency in North Western Himalaya

Shweta Sharma, Anjali, Shilpa Kumari and Pardeep Kumar*

Department of Soil Science, College of Agriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur – 176062, India; drpardeep1968@gmail.com

Abstract

Two-year field studies were conducted during *kharif* 2023 and 2024 at CSKHPKV Experimental Farm, Palampur, to assess maize response to soil-applied boron (B) (SB_0: 0, SB_3: 3, SB_6: 6, SB_9: 9 and SB_{12}: 12 kg B ha^{-1}) and foliar frequencies (0.034%; F_0: 0, F_2: 2, F_3: 3) under inherently B-deficient acid soils. During 2023, maximum grain and stover yields were registered with 3 kg B ha^{-1} + 2 foliar sprays. In contrast, during 2024 and on the pooled basis, foliar sprays produced statistically similar responses, suggesting that the crop's demand was largely met from soil-applied B. The highest productivity-profitability ratio (PPR) was accounted for with 3 kg B ha^{-1} along with 2 frequencies. Conversely, internal B use efficiency (IBUE) was maximum under the Recommended Dose of Fertiliser (RDF) irrespective of years, followed by 3 kg B ha^{-1}, applied either solely or with or without sprays, indicating diminishing returns at higher B inputs.

Keywords: Boron, Internal B Use Efficiency, Productivity, Profitability Ratio

Heavy emphasis on macronutrient additions has undoubtedly raised crop productivity, but has also masked the vital contribution of micronutrients. These micro elements are potential contributors in shaping the crop productivity as well as the profitability, which forms the topmost priority of the growers[1]. Although such nutrients are required in trace amounts, they demand macro attention. Of late, boron (B) has caught major attention and has emerged as the second most deficient micronutrient after zinc in the country as well as globally, reflecting an alarming situation[2]. Particularly, regions experiencing high rainfall coupled with high temperature, acid soils (pH < 5.5) and coarse texture favour its removal from the soil, perfectly resembling the experimental soils (Palampur region) of NW Himalaya[3]. The site receives heavy rainfall, which can further accelerate B losses through leaching[4]. While basal soil B application is widely acknowledged among farmers, its efficiency is very low (< 5%)[5] and is liable to leaching. So, foliar feedings in conjunction with soil application can compensate for these losses from soil and can meet the crop demand at later growth stages. However, foliar application cannot be done at an early growth stage until the crop attains a good stand and foliage. Further, frequent sprays are required to make it available at critical growth stages. Therefore, foliar sprays at sensitive stages can complement soil application to correct the deficiencies

*Author for correspondence

Manuscript received: 06.01.2026; Accepted: 30.03.2026

and maintain the optimum availability of B throughout the growing period. Furthermore, B content in Indian soils has been reported to vary between 7 and 630 mg kg^{-1}. Surprisingly, out of which only a small fraction (0.75–8.0 mg kg^{-1}) is readily available to plants owing to limited water solubility[6]. Continuous removal through intensive cropping without matching replenishment has further exacerbated soil and crop deficiencies. Consequently, regions once considered sufficient are now designated as deficient zones[7] and produce poor outcomes in terms of yield and monetary returns. A major concern in such soils arises that, with low plant-available B and intensive cropping, how can crop productivity and farmer profitability be sustained?

Moreover, highly variable crop responses to external B fertilisation make its management a challenging aspect, especially for the sensitive B-demanding crops. Among these, maize (*Zea mays* L.), a major cereal grown in this zone, is particularly vulnerable to B deficiency as its cob initiation and grain formation require adequate B, making it an early indicator of B imbalance. Deficiency manifests as irregularly aligned grains, short and bent cobs, malformed tips and poor kernel development[8]. But under adequate management, as evident by work done by Baghel[9] in similar silty clay loam soils of Palampur, maximum yield outcomes and economic returns in maize were registered with 2.5 kg B ha^{-1} coupled with two foliar sprays. However, managing B is very challenging owing to the thin line between its deficiency and toxicity[10]. Consequently, yield responses with B rarely follow a linear trend. Rather, productivity typically increases proportionately only up to an optimum level and thereafter diminishes once B surpass the crop's physiological tolerance, particularly in sensitive crops like maize. Furthermore, the nutrient use efficiency is one of the major deciding factors of the economic viability of a system. This raises a critical question that which B application rates can sustain yields while being economically viable to farmers?

To address this, field experiments were conducted, aiming to assess the impact of conjoint soil and foliar mediated B application on yield enhancement, productivity, profitability and use efficiency. We hypothesised that under B-deficient soils, moderate soil application coupled with multiple foliar intervals would yield better results.

MATERIALS AND METHODS

The present study was undertaken at the experimental farm, Department of Soil Science, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India, during *Kharif* 2023 and 2024. The site is exposed at an elevation of 1290 m (32°06′ N, 76°03′ E) within the mid-hill wet temperate zone (Zone II) of the North Western Himalaya. As per Koppen-Geiger climate maps[11], the region falls in Cwa, which stands for C (temperature), w (dry winter), and a (hot summer), categorised as a monsoon-impacted humid-subtropical climate. About 75% of the region's average annual rainfall of 2500 mm occurs from June to September. The average maximum temperature during the hottest months of May and June is about 21.6˚C, while the minimum drops to about 12˚C during the coldest months from December to February. The experimental soil exhibited silty clay loam texture and an acidic pH of 4.5. Initially, the soil's available nutrient contents, *viz*., NPK and B, were 318, 49.5 and 180 kg ha^{-1} and 0.370 mg kg^{-1}, respectively.

The study tested five graded doses of soil-applied B (SB_0: 0, SB_3: 3, SB_6: 6, SB_9: 9 and SB_{12}:12 kg B ha^{-1}) coupled with three foliar frequencies of 0.034 % ($F_{0:}$ 0, $F_{2:}$ 2 and $F_{3:}$ 3) at knee-high, tasselling and grain filling stages. Accordingly, fifteen treatment combinations were formed and laid out in a factorial randomised block design, along with one recommended dose of fertiliser (RDF: N:120; P_2O_5: 60; K_2O: 40 kg ha^{-1}) as a separate control. FYM @ 10 tonnes ha^{-1} was applied uniformly in all treatments in both seasons except RDF. Soil application of B was done through borax,

while foliar *via* boric acid. All standard cultural operations were strictly adhered to during the entire crop period. The observations were recorded on grain and stover yields: The cobs from each net plot were dehusked and sun-dried. After sun drying and shelling, the grains obtained were cleaned and weighed. From the weight of grains per plot, the yield was determined in tonnes per hectare. The stover yield was computed by deducting the weight of the threshed grains from the total biological yield and expressed in tonnes per hectare.

$$\text{Productivity} - \text{Profitability ratio (PPF)}: \frac{[\text{Grain yield (tonne s/h a)} * 1000]}{\text{Cost of cultivation (₹/h a)}}$$

$$\text{Internal B use efficiency (IBUE)}: \frac{[\text{Grain yield (tonne s/h a]}}{\text{Total B uptake}}$$

The data were analysed following the technique of analysis of variance for randomised block design as outlined by Gomez and Gomez[12] using Microsoft Excel.

RESULTS AND DISCUSSION

Grain Yield

Tested doses of B produced significantly prominent yield outcomes across both experimental years (Table 1). During 2023, the highest yield was achieved with moderate application of 3 kg B ha^{-1} (5.16 tonnes ha^{-1}) and maintained statistical comparability with 6 kg B ha^{-1} (4.80 tonnes ha^{-1}). This moderate dose might have provided a sustained and adequate supply of B and satisfied the crop demand throughout the entire crop cycle. Conversely, a negative response was registered with higher doses of 9 (4.69 tonnes ha^{-1}) and 12 kg B ha^{-1} (4.37 tonnes ha^{-1}). Earlier work done also indicated that increased B application in soil beyond a critical level becomes toxic to the crop, as the range between sufficiency and toxicity is very narrow[4]. In similar silty clay loam soils, Nazir *et al.*,[13] reported 2.7 kg B ha^{-1} as the optimum rate for enhancing cauliflower productivity, but exhibited an inverse response with further increase in doses up to 30 kg B ha^{-1}. Interestingly, in our study, yield under B omitted treatment (SB_0) surpassed the highest dose (SB_{12}) by **2**%, demonstrating the deleterious impact of excessive application. Therefore, a decline in yield with distorted nutrient application raises concerns regarding potential toxicity to the crop. Supporting this, Laik *et al.*,[14], under calcareous soils of Bihar, witnessed an increase in rice and mustard yields with the use of 2 kg B ha^{-1}, in alternate years. Conversely, in acid sandy loam soils of Orissa, Jena *et al.*,[15] reported maximum rice grain output with an annual application of 0.5 kg B ha^{-1}. Conversely, in 2024, 6 kg B ha^{-1} gave significantly lower yield (4.79 tonnes ha^{-1}) over 3 kg (5.18 tonnes ha^{-1}) and again declined beyond 6 kg, reaching the least value under 12 kg B ha^{-1} (4.32 tonnes ha^{-1}). Further, the pooled data clearly confirmed this response pattern, where even no application (SB_0) produced numerically higher yield of 4.5 tonnes ha^{-1} compared to 4.34 tonnes ha^{-1} with 12 kg B ha^{-1} (SB_{12}). While 3 kg B ha^{-1} registered the highest yield of 5.17 q ha^{-1}, it caused an improvement of 31 % over 12 kg B ha^{-1}. As B plays a paramount role in vital physiological and biochemical processes in plants, including nucleic acid synthesis, calcium absorption, starch metabolism, nitrogen and phosphorus utilisation, and movement of assimilates from sources to sinks, it ultimately boosts the crop productivity[16].

Foliar frequencies of B also exerted a significant influence but only during the first year (2023), where plots fed with 2 sprays produced the highest yield (F_2, 4.92 tonnes ha^{-1}), which was significantly superior to the control treatment (4.51 tonnes ha^{-1}). While 3 frequencies (F_3, 4.66 tonnes ha^{-1}) produced statistically similar results. Contrarily, during 2024, yield differences were non-significant, although twice feeding (4.78 q ha^{-1}) maintained numerical superiority over SB_0 (4.63 tonnes ha^{-1}) and F_3 (4.61 tonnes ha^{-1}), indicating a diminishing treatment effect in the second season. A similar response pattern was followed on a pooled basis.

Moreover, across both seasons as well as on a pooled basis, the interaction between imposed soil and foliar treatments produced statistically consistent results. In parallel to our findings, Baghel *et al.*,[17] recommended the conjoint use of 2.5 kg B ha^{-1} + two foliar sprays for

Table 1. Effect of conjoint soil and foliar application of B on grain and stover yields of maize (tonnes ha^{-1})

Treatments	Grain yield (tonnes ha^{-1})			Stover yield (tonnes ha^{-1})		
	2023	2024	Pooled	2023	2024	Pooled
Soil B levels (kg ha^{-1})						
SB_0	4.47	4.53	4.50	6.62	6.65	6.63
SB_3	5.16	5.18	5.17	7.37	7.48	7.43
SB_6	4.80	4.79	4.80	6.91	7.21	7.06
SB_9	4.69	4.52	4.60	6.87	6.76	6.81
SB_{12}	4.37	4.32	4.34	6.54	6.31	6.42
LSD ($p \leq 0.05$)	0.38	0.33	0.30	0.37	0.39	0.35
Foliar frequencies (0.034%)						
F_0	4.51	4.63	4.57	6.74	6.79	6.77
F_2	4.92	4.77	4.85	7.08	7.00	7.04
F_3	4.66	4.61	4.63	6.76	6.85	6.80
LSD ($p \leq 0.05$)	0.29	NS	NS	0.29	NS	NS
RDF v/s other treatments						
RDF	4.70	4.67	4.68	6.86	6.88	6.87
Other treatments	3.61	3.83	3.72	5.65	5.97	5.81
LSD ($p \leq 0.05$)	0.48	0.40	0.37	0.51	0.48	0.46

harnessing maximum yield outputs in maize grown under similar acid soils. In contrast, Phonglosa *et al.*,[18] reported the highest grain yield of maize with 0.5 kg B ha^{-1} + 0.2% foliar spray in B-deficient soils. Comparing the other treatments with the RDF, poor yield performances were evidenced under B-devoid RDF treatments, emphasising the critical role of B in sustaining the crop productivity[19]. B fertilisation improves cereal pollination by minimising sterility, optimising pollination and enhancing grain fertility, ultimately leading to increased grain count, which might have increased the yield. Further, yield increase in other treatments over RDF was maximum in 2023 (30.2 %), slightly lower in 2024 (21.9 %) and 25.8% on a pooled basis, reflecting a consistent treatment effect.

Stover Yield

A clear build-up in stover biomass was witnessed up to 3 kg B ha^{-1}, producing 7.37 and 7.48 tonnes ha^{-1} during 2023 and 2024, causing an increase of 11.3 and 12.5 % over control (SB_0), respectively (Table 1). In alignment with our results, work done by Sharma *et al.*,[20] also reported that 2–3 kg B ha^{-1} significantly increased maize stover yield, which might be attributed to its role in improving cell wall formation and photosynthetic efficiency. In this study, raising the dose beyond 3 kg B ha^{-1} proved counterproductive, as yield declined under 12 kg B ha^{-1}, dropping to 6.54 and 6.31 tonnes ha^{-1}, which corresponded to a reduction of 12.6 and 18.5 % compared to 3 kg B ha^{-1}. These findings maintained corroboration with results of Rehman *et al.*,[21] who observed reduced maize biomass at 12 kg B ha^{-1} and

documented that a threshold exists beyond which B application becomes counterproductive, emphasising the need for precise nutrient management. On the pooled basis, the same dose-maintained superiority producing 7.43 tonnes ha^{-1}, while 12 kg B ha^{-1} registered the minimum biomass production of 6.42 tonnes ha^{-1}.

Unlike soil application, the response with foliar application was inconsistent. In 2023, application of 2 sprays (F_2) caused an increase of 5.0 % over spray-devoid plots (F_0), whereas 3 sprays (F_3) produced no significant change. Contrastingly, Khan *et al.*,[22] in B-deficient soils observed enhanced maize stover yield with 3 foliar feedings of B. In the current study, statistically comparable responses with F_3 might be due to environmental factors affecting foliar absorption, such as rainfall, humidity or plant growth stage[23] or due to satisfied crop demand. Gupta *et al.*,[24] also reported variable responses in maize with foliar B depending on timing and frequency of sprays. However, yields in 2024 and pooled analysis exhibited statistically comparable results; plots fed twice (F_2) had a slight numerical edge over three (F_3) and no spray treatments (F_0). Furthermore, the interaction between tested soil and foliar treatments produced statistically stable yields across years as well ason the pooled basis. The values in other treatments significantly surpassed RDF by 21.4, 15.2 and 18.2 %, respectively, in 2023, 2024 and on the pooled basis. Soil-applied B might have supported early vegetative growth and root development, while foliar sprays supplied B during critical stages when soil uptake was limited by boron's low mobility in plants, enhancing cell wall formation, leaf expansion, and photosynthetic efficiency, lignification and photosynthetic activity, resulting in increased stover accumulation[25].

Productivity-Profitability Ratio (PPR)

PPR was markedly influenced by conjoint soil and foliar application of B during both years and in the pooled analysis (Table 2). Across treatments, PPR values ranged from 0.083 to 0.120, indicating clear variation in economic efficiency arising from different B management. This variation was due to the variable yield responses and costs incurred across the treatments. Furthermore, S_3F_2 consistently recorded the highest PPR during 2023 (0.120), 2024 (0.113) and on the pooled basis (0.116) and least with $S_{12}F_3$ (0.085, 0.083 and 0.084, respectively). The superior performance of S_3F_2 suggested that a moderate dose of soil B, supplemented with timely foliar sprays at critical growth stages, might have ensured its adequate availability for crop growth and grain development. At the same time, input costs remained within an economically viable range, resulting in higher net returns. Treatments receiving 3 kg B ha^{-1} outperformed both the control (SB_0) and higher tested levels (6, 9 and 12 kg B ha^{-1}). This trend indicated that maize responded positively to B application only up to an optimum level, beyond which the economic advantage declined. The gradual reduction in PPR at higher B doses could be attributed to increased expenditure on B fertilisers without a commensurate increase in grain yield.

In addition, excessive inputs caused sub-optimal physiological responses and produced low yields and reduced profitability. Singh *et al.*,[26] reported that maize treated with B recorded significantly higher yield and B:C compared to control plots, revealing the economic edge of micronutrient inclusion. Similarly, Pinninti *et al.*,[27] demonstrated that foliar sprays of B enhanced maize growth and yield, which directly contributed to improved economic efficiency. In sweet corn, Ojha *et al.*,[28] reported that the combined use of P and B increased yield and net returns over lower nutrient levels. With respect to foliar frequencies, application of two foliar sprays (F_2) proved more profitable than three (F_3) sprays, as the third spray increased the cost of cultivation without providing proportional yield benefits. This suggests that B application at key growth stages is sufficient to meet crop demand, while excessive offers diminish economic returns. The RDF treatment recorded a moderate PPR value of 0.102 (pooled). Although this treatment involved lower input costs, the absence of B and organic manure limited yield potential, resulting in comparatively lower

Table 2. Effect of conjoint soil and foliar application of B on profitability-productivity ratio and internal B use efficiency

Treatments	Doses	Productivity-Profitability ratio (PPR)			Internal B Use Efficiency (%) (IBUE)		
		2023	2024	Pooled	2023	2024	Pooled
T_1	SB_0F_0	0.089	0.094	0.091	0.258	0.267	0.262
T_2	SB_0F_2	0.096	0.095	0.095	0.266	0.260	0.263
T_3	SB_0F_3	0.100	0.099	0.100	0.261	0.250	0.255
T_4	SB_3F_0	0.101	0.108	0.104	0.289	0.301	0.295
T_5	SB_3F_2	0.120	0.113	0.116	0.298	0.261	0.279
T_6	SB_3F_3	0.104	0.104	0.104	0.259	0.257	0.258
T_7	SB_6F_0	0.098	0.098	0.097	0.236	0.232	0.234
T_8	SB_6F_2	0.102	0.100	0.101	0.220	0.218	0.219
T_9	SB_6F_3	0.100	0.099	0.099	0.210	0.195	0.202
T_{10}	SB_9F_0	0.097	0.098	0.097	0.210	0.204	0.207
T_{11}	SB_9F_2	0.102	0.093	0.097	0.195	0.185	0.190
T_{12}	SB_9F_3	0.091	0.087	0.089	0.169	0.161	0.165
T_{13}	$SB_{12}F_0$	0.091	0.088	0.089	0.180	0.176	0.178
T_{14}	$SB_{12}F_2$	0.091	0.091	0.091	0.167	0.166	0.166
T_{15}	$SB_{12}F_3$	0.085	0.083	0.084	0.153	0.153	0.153
T_{16}	RDF	0.099	0.105	0.102	0.318	0.347	0.332

profitability. The consistent superiority of B-treated plots receiving FYM highlighted the importance of integrated nutrient management. FYM might have improved the physical condition of the soil and nutrient availability and enhanced the effectiveness of applied B and NPK fertilisers. Therefore, the results clearly demonstrated that balanced B nutrition, particularly at 3 kg B ha^{-1} (SB_3) combined with 2 foliar sprays (F_2), optimised both productivity and profitability of maize. Whereas excessive applications increased costs without corresponding yield benefits, emphasising the need for its judicious management.

Internal B Use Efficiency (IBUE)

Response in IBUE under the examined soil and foliar treatments has been presented in Table 2. Notably, RDF treatment registered the highest use efficiency across both years as well as on the pooled basis (0.318, 0.347 and 0.332%, respectively). However, this is just a mathematical outcome rather than a reflection of superior crop performance. This treatment, however, exhibited very low total B uptake from native soil B, and grain yield was also the lowest, so dividing a small yield by an extremely small B uptake inflated the IBUE

value. For instance, in loamy soils, Garnaik *et al.*,[29] in a longterm study on rice, reported that internal nitrogen utilisation efficiency (INUE) was *highest in the unfertilized control system* despite low total N uptake, because the denominator (total N uptake) was very small compared to the yield produced, even if that yield was also modest. Furthermore, IFA[30] reported that extremely high internal utilisation efficiency often occurs under nutrient deficiency conditions, perfectly matching experimental soil, because a crop produces some yield with very low nutrient absorption, which mathematically inflates the efficiency ratio. Singh *et al.*,[31] further confirmed this interpretation in their study, where internal utilisation efficiency exhibited an increase as nutrient uptake by lentil declined, even though absolute yield did not improve significantly. Therefore, the highest observed values under RDF in this study do not indicate superior B use, but rather reflect very low total B uptake from soil. Further, during the same year, S_3F_2 witnessed second highest efficiency of 0.298 %. Conversely, during the second year and on a pooled basis, RDF was followed by S_3F_0 with 0.301 and 0.295 %, respectively. Work done by Ma *et al.*,[32] further demonstrated that the seed yield of rapeseed responded significantly to B fertilisation as a consequence of enhanced B remobilisation efficiency compared to zero-B controls. Therefore, S_3F_2 emerged as an effective combination that increased both yield and total B uptake, resulting in lower IBUE values but clearly demonstrated better agronomic and economic performance. Rather, it is a mathematical consequence of very low total B uptake under deficiency, which resulted in a large yield per unit B ratio.

CONCLUSIONS

Conjoint application of 3 kg B ha^{-1} and 2 foliar frequencies produced significant improvements in grain and stover yields of maize during the first year of study. However, during subsequent years and on a pooled basis, foliar sprays did not cause any significant impact on the yield. Raising the rates beyond 3 kg B ha^{-1} and 2 sprays caused a significant reduction in both yields and productivity profitability ratio. Contrastingly, maximum internal B use efficiency was recorded under RDF, followed by 3 kg B ha^{-1} applied either alone or integrated with 2 foliar sprays.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

1. Sharma S, Sharma SK, Kumar P. Productivity and profitability of soybean as influenced by phosphorus and molybdenum fertilization in an acid Alfisol. Himachal J Agric Res. 2024; 50(2):261-267. https://hjar.org/index.php/hjar/article/view/172598
2. Rana M, Sankhyan NK, Thakur P, et al. Molybdenum in soil-plant system: bioavailability, dynamics and implications for sustainable crop production. Discover Soil. 2025; 2:89. https://doi.org/10.1007/s44378-025-00118-4
3. Shukla AK, Behera SK. Micronutrients research in India: retrospect and prospects. In: FAI Annual Seminar (Preprint). Vol. 10; 2017.
4. Thakur P, Kumar P, Shukla AK, Butail NP, Sharma M, Kumar P Sharma U. Quantitative, qualitative and energy assessment of boron fertilization on maize production in North-West Himalayan region. Int J Plant Prod. 2023; 17(1):165-176. https://doi.org/10.1007/s42106-023-00235-6
5. Sarkar D, Mandal B, Kundu MC. Increasing use efficiency of boron fertilisers by rescheduling the time and methods of application for crops in India. Plant Soil. 2007; 301(1):77-85. https://doi.org/10.1007/s11104-007-9423-1
6. Prasad R, Kumar D, Shivay YS, Rana DS. Boron in Indian agriculture: A review. Indian J Agron. 2014; 59(4): 511-517.
7. Basumatary A, Bhupenchandra I, Chauhan S, Choudhary AK, Goswami K. Synergistic influence of sulphur and boron fertilization on enhancing the productivity of rapeseed (*Brassica napus* L.) and nutrient status in subtropical acidic soil of Assam, India. Commun Soil Sci

Plant Anal. 2022; 53(12):1498-1517. https://doi.org/10.1080/00103624.2022.2055052

8. Dell B, Huang L. Physiological response of plants to low boron. Plant Soil. 1997; 193(1):103-120. https://doi.org/10.1023/A:1004264009230
9. Baghel C, Sankhyan NK, Kumar N, Gautam S, Butail NP, Kashyap M, Bahman M. Impact of boron and molybdenum applications on growth and yield attributes of maize (Zea mays L.) in an acid soil. Himachal J Agric Res. 2025; 51(1):94-98.
10. Jokanović, MB. Boron toxicity and deficiency in agricultural plants. Int. Journal Mol Sci. 2020; 21(4): 1424. https://doi.org/10.3390/ijms21041424
11. Peel MC, Finlayson BL, McMahon TA. Updated world map of the Köppen-Geiger climate classification. Hydrol Earth Syst Sci. 2007; 11(5):1633-1644. https://doi.org/10.5194/hess-11-1633-2007 PMCid: PMC10809878.
12. Gomez KA, Gomez AA. Statistical procedures for agricultural research. New York: John Wiley and Sons. 1984; pp. 357-427.
13. Nazir G, Kumar P, Shukla AK, Sharma U. Cauliflower (*Brassica oleracea* var. *botrytis* L.) growth, yield and quality as influenced by variable rates of boron. J Environ Biosci. 2017; 31(1):33-39.
14. Laik R, Singh SK, Pramanick B, Kumari V, Nath D, Dessoky, ES, Attia AO, Hassan MM, Hossain, A. Improved method of boron fertilization in rice (*Oryza sativa* L.)–mustard (*Brassica juncea* L.) cropping system in upland calcareous soils. Sustainability. 2021; 13(9): 5037. https://doi.org/10.3390/su13095037.
15. Jena B, Mohapatra S, Nayak RK, Das J, Shukla AK. Effect of boron fertilization on fate of soil boron pool under a rice-vegetable cropping system grown in an Inceptisol of Odisha. Int J Chem Stud. 2017; 5(1):74-78.
16. Bayar J, Shah S, Khan W, Okla MK, Alwasel YA, Saleh IA, AbdElgawad H, Rahim W, Iqbal B, Jalal A. Boron foliar application improves growth, yield and grain quality of maize. Pol J Environ Stud. 2024; 33(3):3079-3089. https://doi.org/10.15244/pjoes/177183
17. Baghel C. Effects of boron and molybdenum application on their dynamics and maize-cauliflower productivity in an acid Alfisol [PhD thesis]. Palampur (HP): CSK Himachal Pradesh Krishi Vishvavidyalaya; 2025.
18. Phonglosa A, Dalei BB, Nayak RK, Pattanayak SK, Kropi J, Saren S. Response of boron on yield and economics of maize under Eastern Ghat High Land zone of Odisha. Int J Agric Environ Biotechnol. 2019; 12(1):33-37. https://doi.org/10.30954/0974-1712.03.2019.6
19. Shukla A, Singh R, Singh SK, Shukla DM, Singh R. Study the effect of boron levels on yield attributes of rice crop. J Pharmacogn Phytochem. 2020; 9(6):730-733. https://doi.org/10.22271/chemi.2020.v8.i5k.10389
20. Sharma A, Sharma RP. Effect of boron and lime on productivity of garden pea under acidic soils in north-western Himalayas. Commun Soil Sci Plant Anal. 2016; 47(3):291-297. https://doi.org/10.1080/00103624.2015.1122798
21. Rehman H, et al. Boron toxicity effects on maize growth and nutrient dynamics. J Soil Sci Plant Nutr. 2017;17(2):400-412.
22. Khan M, Ahmed S, Ali A, Hussain M, Raza A. Influence of foliar boron sprays on maize productivity under boron-deficient soils. Agric Sci. 2020; 11:1123-1133.
23. Alloway BJ. Boron in soils and plants. Dordrecht: Springer; 2008. 247 pp. ISBN: 978-1-4020-5381-0.
24. Gupta R, Sharma P, Kumar S. Foliar boron application in maize: yield and nutrient uptake response. J Plant Nutr. 2019; 42(15):1750-1761.
25. Haque MA. The effects of foliar boron on the growth and yield of maize. Int J Plant Soil Sci. 2025; 37(4):97-103. https://doi.org/10.9734/ijpss/2025/v37i45391
26. Singh S, Singh V, Mishra P. Effect of NPK, boron and zinc on productivity and profitability of late sown kharif maize (*Zea mays* L.) in western Uttar Pradesh, India. Ann Agric Res. 2018; 38(3):000-000.
27. Pinninti AK, Mehera B, Kumar P. Effect of foliar application of boron and silicon on growth and yield of maize (*Zea mays* L.). Int J Plant Soil Sci. 2023; 35(14):256-262. https://doi.org/10.9734/ijpss/2023/v35i143043
28. Ojha AK, Dawson J, Rana A. Effect of phosphorus and boron on growth, yield and economics of sweet corn (*Zea mays* L.). Int J Plant Soil Sci. 2023; 35(9):91-98. https://doi.org/10.9734/ijpss/2023/v35i92909
29. Garnaik S, Samant PK, Nayak J, Sahu S. Nitrogen use efficiency and micronutrient uptake under a long-term paddy production. Pharma Innovation J. 2022; SP-11(9):2191-2197.
30. International Fertilizer Association. Nutrient/fertilizer use efficiency: definitions and application. Paris: International Fertilizer Association; 2014. Chapter 1. fertilizer.org

31. Singh A, Jaswal A, Singh M. Enhancing nutrient use efficiency in crops (section on internal utilization efficiency). Agric Rev. 2019; 40(1):65-69.

32. Ma X, Li Y, Zhang H, Wang J, Liu Z. Surplus boron nutrition enhances accumulation in plant residues, canopy radiation interception and yield of winter direct seeding rapeseed in Southwestern China. Sci Rep. 2025; 15:19306. https://doi.org/10.1038/s41598-025-19306-x PMid: 41068300 PMCid: PMC12511452.

AUTHORS CONTRIBUTION

SS: conducted the experiment, analyzed the data and wrote the original manuscript. A and SS: reviewed and edited the manuscript. PK: conceptualized the research programme, methodology, provided resources, reviewed and edited the manuscript.