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Impact of boron and molybdenum applications on growth and yield attributes of maize (*Zea mays* L.) in an acid soil

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Abstract

A field experiment was conducted to assess the impact of boron (B) and molybdenum (Mo) applications on the agronomic traits of maize. The experiment comprised two factors with four levels each of B and Mo, arranged in factorial randomized block design with three replications. The soil+foliar application approach using either B or Mo significantly enhanced plant height, dry matter accumulation, cob length, rows per cob, and overall maize yield. Foliar feeding was more effective in improving growth and yield attributes over soil application of studied micronutrients. Individually, B application resulted in higher grain and stover yields of maize compared to Mo, identifying its greater importance in maize nutrition. However, no significant interaction was observed between the B and Mo tested treatments.

Keywords: Micronutrients, agronomic traits, fertilizer application approaches, nutrient deficiency

Maize (*Zea mays* L.), a primary cereal crop, grown for food, feed and fodder production occupies a pride place after wheat and rice globally (Klopfenstein *et al*., 2013). Owing to its high genetic potential and nutrient exhaustive nature, it requires substantial quantities of both macro and micronutrients for optimum growth and development (Deshmukh *et al*., 2008). Application of large amounts of N, P, and K fertilizer without any organic inputs has exacerbated multi-micronutrient deficiencies in soils resulting in poor maize growth. Micronutrient management is therefore critical within food systems, as their integration into a balanced fertilization schedule can optimize their supply and availability throughout the consumption-production cycle.

Micronutrients are required in modest amounts but still play a pivotal role in plant physiology, especially boron (B) and molybdenum (Mo). B application helps in cell wall formation, lignification, xylem differentiation, pollen germination, carbohydrate metabolism and their translocation. Whereas, Mo is associated with the structural component of nitrogenase enzyme, protein biosynthesis, and the formation along with viability of pollen and anther, making it crucial for plants. Deficiencies of both disrupt biochemical and physiological processes, further inhibiting plant growth and development. Studies related to B and Mo application either through soil or foliar approach improved crop growth (Vishekaii *et al*., 2019; Prado *et al*., 2023). Interestingly, Thakur *et al*. (2024) demonstrated that foliar spray of B significantly improved broccoli yield over its soil application. Similarly, foliar application of Mo enhanced yields across various crops (Abobatta *et al*. 2024). The studies highlighted the efficacy of foliar applications, attributed to the direct and efficient nutrient absorption through plant leaves. Based on the premise, it was anticipated that foliar applications of B or Mo would outperform soil applications in promoting crop growth and yield. However, the combined effects of both applied through different methods, remained unexplored. To address this gap, an experiment was conducted to evaluate the effects of boron and molybdenum applications on maize growth and yield attributes, focusing on the nutrient interactions and their physiological impacts.

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Materials and methods

The experiment was laid out to evaluate the combined effect of B and Mo at the experimental farm, Department of Soil Science, CSK HPKV, Palampur during *kharif* 2022. The soil of the experimental site was characterized as silty clay loam in texture, while the total rainfall received during this period was about 309.5 mm. The layout employed for experimentation was factorial randomized block design comprising two factors, each having four levels, and replicated thrice. The factor-I (B) comprised of no B, soil applied B (2.5 kg B ha^{-1}), foliar B (0.034% B), and soil + foliar B, similarly the factor-II (Mo) consisted of no Mo, soil applied Mo (2.5 kg Mo ha^{-1}), foliar Mo (0.10% Mo), and soil + foliar Mo. The treatment involving soil+foliar application consisted of combined soil dose and foliar spray, both applied at same concentration as their respective sole levels. The application of B and Mo as foliar sprays were performed twice, first at the knee high and second at the tasseling stage. The standard dose of NPK fertilizer (120:60:40 kg ha^{-1}) was applied uniformly in all plots, as per the recommendation. Five plants were randomly tagged per plot to determine growth and yield attributes except dry matter. A single plant was selected from the gross area of each plot for determining dry matter. The plant height and dry matter were recorded at three stages (knee high, tasseling and maturity), while remaining attributes (number of plants per square meter, number of cobs per plant, number of cobs per hectare, cob length and number of rows per cob) were determined at the time of harvest. The grain and straw yields were recorded from the net plot and multiplied with the factor 11.57 to convert recorded yield into "q/ha". The interaction between B and Mo showed non-significant effect on any of the measured attributes so, only the individual effects of the studied factors are presented in the results.

Results and discussions

The recorded plant height was significantly affected with the application of B as well as Mo (Table 1). The plants at knee high, tasseling and harvest stage showed a range from 63.8 to 73.5, 224.4 to 264.3 and 237.7 to 274.5 cm, respectively. The treatment that received soil+foliar application of B or Mo resulted in significantly taller plants at the respective critical stages compared to their sole soil or foliar application. In contrast, the lower plant height was recorded under B and Mo deprived treatments. Similar trend was recorded in the dry matter at different stages. Soil+ foliar B application recorded 7.09, 62.9 and 69.3 q ha^{-1} dry matter at knee high, tasseling and harvest stage, respectively. However, same combinations in case of Mo application recorded slightly lower dry matter at knee high (6.46 q ha^{-1}), tasseling (58.6 q ha^{-1}) and harvest (64.9 q ha^{-1}). About

Table 1. Impact of B and Mo application on growth attributes of maize

Treatments		Plant Height (cm)			Dry Matter (q ha^{-1})			No. of plants m^{-2}
		Knee high	Tasseling	Harvest	Knee high	Tasseling	Harvest	
B levels	No B Applied	65.0^{c}	226.7^{d}	240.0^{d}	6.34^{c}	57.1^{c}	63.4^{c}	6.81
	B Applied to Soil	68.8^{b}	234.7^{c}	248.0^{c}	6.57^{b}	60.1^{b}	66.4^{b}	7.08
	B Applied as Foliar Spray	65.2^{ab}	241.6^{b}	254.9^{b}	6.34^{c}	61.5^{ab}	67.8^{ab}	6.94
	Soil + Foliar B Applied	71.2^{a}	251.8^{a}	264.3^{a}	7.09^{a}	62.9^{a}	69.3^{a}	7.64
Mo levels	No Mo Applied	66.0^{B}	231.6^{C}	244.9^{C}	6.46^{B}	58.6^{C}	64.9^{C}	7.08
	Mo Applied to Soil	68.0^{AB}	236.6^{BC}	249.9^{BC}	6.60^{AB}	60.0^{BC}	66.4^{BC}	6.81
	Mo Applied as Foliar Spray	66.0^{B}	240.4^{AB}	253.7^{AB}	6.50^{B}	60.9^{AB}	67.2^{AB}	7.22
	Soil + Foliar Mo Applied	70.1^{A}	246.2^{A}	258.7^{A}	6.79^{A}	62.1^{A}	68.4^{A}	7.36
B x Mo levels		NS	NS	NS	NS	NS	NS	NS

Note: Values followed by different lowercase and uppercase letters across different attributes are significantly different within the respective level while values without letters within an attribute indicate no significant difference at a p-value $\leq$ 0.05. B applied to soil, 2.5 kg ha^{-1}; B applied as Foliar spray, 0.034%, Mo applied to soil: 2.5 kg ha^{-1}, Mo applied as Foliar spray, 0.10 %; Soil+ Foliar B Applied, 2.5 kg B ha^{-1}+0.034% B; Soil+ Foliar Mo Applied, 2.5 kg Mo ha^{-1}+0.010%Mo

1% increase in dry matter was recorded at all the stages with the application of B over Mo. At tasseling, the foliar application of either B or Mo showed statistical parity with respective nutrient devoid treatments, in plant height as well as dry matter. A substantial increase in plant height and dry matter was observed from the knee- high to the tasseling stage, while only a slight increase was recorded from the tasseling to harvest across all treatments. The number of plants per square meter remained unaffected by the application of B and Mo. The numerical count ranged from 6.81 to 7.64, where the lowest count was recorded in Mo applied to soil as well as to the B devoid plots.

Application of B and Mo showed positive impact on maize yield attributes. The number of cobs per hectare ranged from 73056 to 92963 in B treated plots, whereas it varied from 74722 to 89259 under Mo applied plots. The cob length was significantly affected by the application of B and Mo. The treatment receiving neither B (18.3 cm) nor Mo (19.7 cm) showed smaller cobs, whereas the soil+foliar application of B (23.1 cm) as well as Mo (22.3 cm) resulted in longer cobs. The cob length showed an increase of about 16% and 8% under the foliar application of B and Mo, respectively, compared to untreated plots. The rows per cob significantly increased by the application of B, likewise Mo also showed an increase compared to untreated plots.

Across all the B levels, the number of rows per cob ranged from 13.2 to 16.4. The highest count was observed under soil+foliar application followed by foliar and lastly under soil B application. While analyzing the individual effect of Mo, no significant difference was observed among all the treatments. The Mo application approach followed the trend for number of rows per cob: soil+foliar > foliar > soil > no Mo.

Grain yield directly reflects the effectiveness of nutrient management practices and genetic potential of crops. In this study, different application approaches for B or Mo significantly improved grain and stover yields, highlighting their importance in maize production. The maize grain yield ranged from 45.9 to 51.7 q ha^{-1}, while stover yield varied from 57.5 to 64.1 q ha^{-1}. An enhancement of 12.6 % in grain yield was recorded with combined application of soil B @ 2.5 kg ha^{-1} alongside foliar sprays of 0.034% B over B devoid treatments. However, only 7.3% increase was recorded with similar treatment receiving Mo over untreated plots. The overall stover yield ranged from 57.5 to 64.1 kg ha^{-1} by the application of different treatments and highest was recorded under the soil + foliar B application showing an increase of about 10% over B untreated plot. Also, an increase of only about 5.7% was observed under the treatment comprising soil + foliar Mo application compared to plots without Mo. While comparing the soil and foliar application approach, the maize yield and other attributes consistently outperformed foliar application, irrespective of nutrient applied.

The increased maize growth and yield attributes with the application of B or Mo might be due to their vital role in the plant physiological processes and metabolic activities (Bittner, 2014; Fleischer *et al.*,

Table 2. Yield attributes of maize as Influenced by B and Mo Fertilization

	Treatments	Number of cobs per hectare	Cob length (cm)	Number of rows per cob
B levels	No B Applied	73056	18.3^{d}	13.2^{d}
	B Applied to Soil	83704	20.7^{c}	14.6^{c}
	B Applied as Foliar Spray	78148	22.0^{b}	15.7^{b}
	Soil + Foliar B Applied	92963	23.1^{a}	16.4^{a}
Mo levels	No Mo Applied	74907	19.7^{D}	13.9^{D}
	Mo Applied to Soil	74722	20.7^{C}	14.8^{C}
	Mo Applied as Foliar Spray	88982	21.4^{B}	15.3^{B}
	Soil + Foliar Mo Applied	89259	22.3^{A}	15.9^{A}
B x Mo levels	NS	NS	NS	

Note: Values followed by different lowercase and uppercase letters across different attributes are significantly different within the respective level while values without letters within an attribute indicate no significant difference at a p-value ≤ 0.05. B applied to soil, 2.5 kg ha^{-1}; B applied as Foliar spray, 0.034%, Mo applied to soil: 2.5 kg ha^{-1}, Mo applied as Foliar spray, 0.10 %; Soil+ Foliar B Applied, 2.5 kg B ha^{-1}+0.034%B; Soil+ Foliar Mo Applied, 2.5 kg Mo ha^{-1}+0.010%Mo

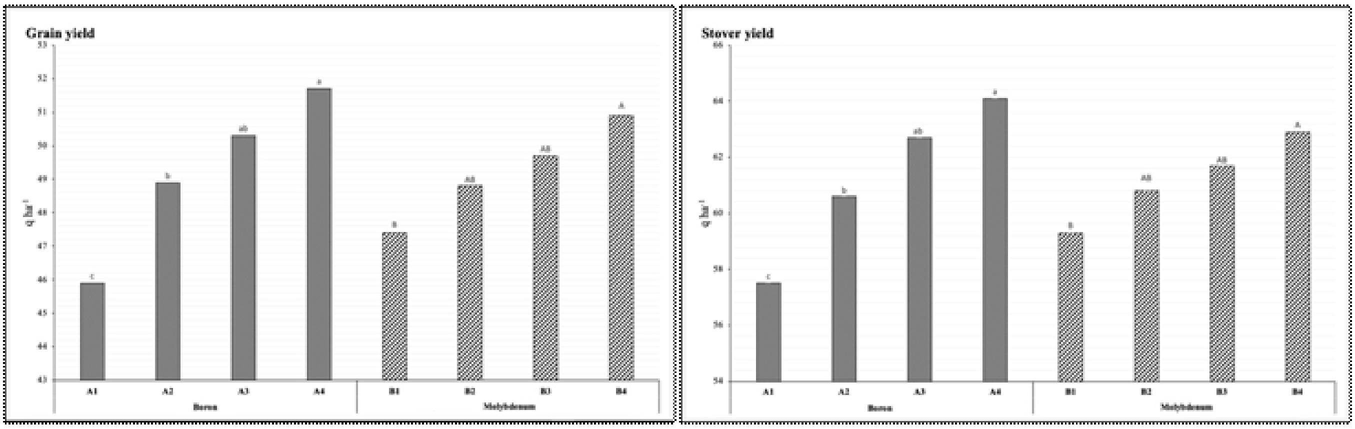

Fig. 1 Effect of B and Mo application approaches on grain and stover yield of maize. A1: No B, A2: Soil (2.5 kg B ha^{-1}), A3: Foliar (0.034% B), A4: Conjoint application of B (Soil + Foliar), B1: No Mo, B2: Soil (2.5 kg Mo ha^{-1}), B3: Foliar (0.10 % Mo), B4: Conjoint application of Mo (Soil + Foliar). Bars represented by different lowercase and uppercase letters across grain and stover yield are significantly different within the respective level at a p-value $\leq$ 0.05.

1998). The treatment devoid of these nutrients (B or Mo) reduced overall plant growth and yield because of their inadequate supply during the critical growth stages. During the experiment, maize plants recorded maximum height and dry matter content on achieving complete physiological maturity at harvest (Tollenaar and Dwyer 1999). However, the variation in these attributes at different growth stages might be due to the discrepancy in the plant nutrition owing to applied treatments. Padbhushan and Kumar (2014) and Sharma and Sharma (2016) also observed an increase in growth attributes with the application of B in green gram and pea, respectively. Seed solely uses its own food reserve for germination, requiring only water and air from the environment (Santos and Garcia 2023). Since, the cultivar and environmental conditions were uniform across all treatments in the experiment, no significant variation was observed in the number of plants per square meter. Similarly, the cobs per hectare due to huge variation in the numbers (cobs) within a replication of the same treatment resulted in lower F-value thus, indicating non-significant results. The significant improvement in cob length and number of rows per cob with the combined application approach (soil+ foliar) of B or Mo was found superior to other treatments, as the soil application provides a steady supply of nutrients to the roots, while foliar feeding facilitates rapid nutrient absorption, ensuring both immediate and sustained nutrient availability. Thus, the combined approach resulted in enhanced maize growth and yield attributes, further enhancing grain and stover yields. Our results corroborated the findings of Shil *et al*. (2007), where the application of 2 kg ha^{-1} of B as well as Mo enhanced growth and yield attributes in chickpea. Furthermore, the application of both (B and Mo) through foliar spray outperformed soil application, as it offers higher efficacy to get absorbed by the leaves, providing faster uptake and immediate availability. Niu *et al*., (2020) reported that foliar application of fertilizer on leaves can reduce the total amounts of fertilizer applied and achieve high fertilizer efficiency. However, ensuring the long-term availability of these nutrients to plants requires enriching the soil. Thus, soil-based approach enriches the respective nutrient pools, ensuring a sustainable and consistent supply of nutrients for better plant growth and development (Havlin *et al*., 2014). The results highlighted greater significance of B over Mo, attributed to its higher requirement in plant development. Additionally, soils are more susceptible to B deficiency than Mo due to the substantial difference in their sufficiency levels, which resulted in higher response of B fertilization in maize.

Conclusion

The study demonstrated the critical role of B and Mo in improving maize growth and yield attributes. Combined soil and foliar applications of these micronutrients significantly outperformed sole soil or foliar applications. Treatments involving B showed greater efficacy than Mo, indicating higher demand of B in plant development and the vulnerability of soil to B deficiency. Foliar applications ensured rapid nutrient uptake, leading to better and immediate crop performance, which aligns with our hypothesis. Whereas, soil applications enriched nutrient pools, providing sustained availability. Integrating both methods optimized nutrient supply, enhancing plant growth and yield attributes. These results emphasize the importance of balanced micronutrient management for sustainable maize production in an acid *Alfisol*.

Conflict of interest: The authors declare that there is no conflict of interest among the authors in this research paper.

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