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IMPACT OF BORON LEVELS ON THE GROWTH AND YIELD OF WHEAT (TRITICUMA ESTIVUM L.)

Original Article

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ABSTRACT

Background: Wheat (*Triticum aestivum* L.) is a key staple crop in Pakistan, contributing significantly to national food security. However, micronutrient deficiencies, particularly boron (B), are limiting wheat productivity, especially in calcareous soils prevalent across much of the country. Boron plays a critical role in spikelet fertility and grain setting, and its deficiency can lead to poor grain development and lower yield. Appropriate boron management is essential to improve crop performance and maximize returns in deficient soils.

Objective: The study aimed to evaluate the impact of varying soil-applied boron levels on the growth and yield parameters of wheat under field conditions in Tandojam, Sindh, and identify the most agronomically and economically optimal boron application rate.

Methods: A field trial was conducted at the Agronomy Research Farm, Sindh Agriculture University, Tandojam, during the Rabi season of 2023–2024. The experiment followed a randomized complete block design (RCBD) comprising six treatments: 0.0, 2.0, 2.5, 3.0, 3.5, and 4.0 kg B ha^{-1}, each replicated three times. The wheat variety TD-1 was sown using a seed rate of 100 kg ha^{-1}. All treatments, except the control, received uniform doses of NPK (130:80:50 kg ha^{-1}). Growth and yield parameters were recorded from five tagged plants per plot, and statistical analysis was performed using ANOVA with LSD at 0.05 significance level.

Results: Application of boron significantly improved all growth and yield attributes. The highest grain yield was recorded at 4.0 kg ha^{-1} (6700 kg ha^{-1}), followed closely by 3.5 kg ha^{-1} (6625 kg ha^{-1}), while the control produced the lowest yield (5565 kg ha^{-1}). The treatment with 3.5 kg ha^{-1} also showed higher net economic returns compared to 4.0 kg ha^{-1}, making it the most efficient dose.

Conclusion: Boron application significantly enhanced wheat yield in boron-deficient soils, with 3.5 kg ha^{-1} identified as the most effective and economically viable rate for sustainable production.

Keywords: Boron Deficiency, Crop Productivity, Grain Yield, Soil Application, Spike Fertility, Triticum aestivum, Wheat.

INTRODUCTION

Wheat (*Triticum aestivum* L.) stands as a cornerstone of food security in Pakistan, forming an integral part of the national diet and contributing substantially to the agricultural economy. As the country grapples with rising population pressures and climate variability, maximizing wheat productivity has become a critical priority. Among the numerous agronomic and environmental factors that influence wheat yield, balanced nutrient management plays a pivotal role in sustaining crop health and performance (1). While macronutrients have traditionally been the focus of fertilization strategies, micronutrients such as boron—though required in trace amounts—are indispensable for optimal plant function. Boron (B) is a vital micronutrient, essential for several physiological and biochemical processes in plants, including cell wall formation, carbohydrate transport, nutrient mobility, and reproductive development. In wheat specifically, adequate boron availability influences spikelet fertility, grain setting, and overall reproductive success (2,3). A deficiency in boron disrupts these processes, leading to impaired root and shoot development, reduced flowering, and diminished seed formation. Symptoms of boron deficiency in wheat are particularly prevalent in calcareous soils, which dominate much of Pakistan's agricultural land. These soils tend to fix boron, rendering it less bioavailable and thereby limiting its uptake by plants (4,5).

Conversely, excessive boron application can be equally detrimental. High concentrations may cause toxicity symptoms such as leaf chlorosis, necrosis, and reduced photosynthetic activity, ultimately compromising plant growth and yield potential (6). This dual challenge of deficiency and toxicity underscores the necessity of precise boron management. Despite its agronomic importance, boron has not received proportional attention in nutrient management programs within Pakistan's wheat-growing regions. Studies have highlighted boron's involvement in critical cellular functions such as enzyme activation, hormone regulation, and membrane integrity—all of which are essential for successful plant reproduction and stress tolerance (7,8). Therefore, understanding the optimal boron levels that support wheat development without crossing into toxicity thresholds remains a pertinent research gap. Given the scarcity of region-specific recommendations, especially for boron-deficient soils such as those found in Tandojam, Sindh, there is a pressing need to determine boron application levels that can enhance wheat productivity without inducing adverse effects. Field-based studies tailored to local soil characteristics and climatic conditions are vital in guiding sustainable nutrient management practices. In light of this, the present study was designed to evaluate the impact of varying boron application rates on the growth and yield parameters of wheat under field conditions in Tandojam. The objective was to identify a boron dosage that is both agronomically beneficial and economically feasible, contributing to evidence-based strategies for improving wheat yield in boron-deficient soils (9,10).

METHODS

A field-based randomized complete block design (RCBD) experiment was conducted during the Rabi season of 2023–2024 at the Agronomy Research Farm, Department of Agronomy, Sindh Agriculture University, Tandojam, Pakistan. The experimental site is located in a semi-arid region characterized by low annual rainfall, moderate temperatures, and clay loam soil—conditions representative of wheat-growing areas in Sindh. The land was prepared uniformly through standard plowing, harrowing, and leveling practices to ensure consistent seedbed quality across all plots. The trial included six boron treatment levels: 0.0, 2.0, 2.5, 3.0, 3.5, and 4.0 kg B ha^{-1}. Each treatment was replicated in a randomized block design to minimize environmental variability. The wheat variety TD-1 was sown in mid-November at a seeding rate of 100 kg ha^{-1} with a spacing of 23×10 cm between rows and plants. Except for the untreated control group (T0), all plots received a consistent basal application of macronutrients at 130:80:50 kg ha^{-1} of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), respectively. Phosphorus and potassium, along with half the nitrogen and the full boron dose, were incorporated into the soil at the time of sowing. The remaining nitrogen was top-dressed in two equal splits at the tillering and panicle initiation stages to support crop growth at critical developmental phases (11).

To evaluate the effects of boron treatments, five representative and physiologically normal plants per plot were randomly selected and tagged for data collection. Observations were made on various growth and yield parameters, including plant height, tiller count, spike length, grain number, 1000-grain weight, and final grain yield. Data were collected at appropriate growth stages and subjected to statistical analysis using Statistix version 8.1 (Statistix, 2006). A one-way analysis of variance (ANOVA) was employed to identify significant differences among treatment means. Where significance was detected, the Least Significant Difference (LSD) test was applied at a 0.5% probability level to determine treatment effects. This research was conducted in accordance with institutional guidelines and agronomic best practices, ensuring responsible use of chemical inputs to prevent environmental contamination. As no human or animal subjects were involved, ethical approval and informed consent were not required.

RESULTS

The application of varying levels of boron had a significant effect on all measured growth and yield parameters of wheat. Boron application at 4.0 kg ha⁻¹ resulted in the highest performance across most traits. This treatment recorded a maximum plant height of 74.92 cm, spike length of 15.68 cm, grains per spike of 56, seed index (1000-grain weight) of 52.69 g, biological yield of 7515 kg ha^{-1}, and grain yield of 6700 kg ha^{-1}. These outcomes were statistically at par with the 3.5 kg ha^{-1} treatment, which demonstrated slightly lower but comparable values: plant height of 73.81 cm, spike length of 15.44 cm, grains per spike of 55, seed index of 52.23 g, biological yield of 7487 kg ha^{-1}, and grain yield of 6625 kg ha^{-1}. The treatment with 3.0 kg B ha^{-1} showed moderate improvements, producing a plant height of 70.58 cm, spike length of 13.48 cm, 53 grains per spike, seed index of 48.56 g, biological yield of 7111 kg ha^{-1}, and grain yield of 6466 kg ha^{-1}. A noticeable decline in performance was observed at 2.5 and 2.0 kg ha^{-1} treatments. For 2.5 kg ha^{-1}, the plant height was 65.94 cm, spike length 10.96 cm, grains per spike 49, seed index 46.50 g, biological yield 6571 kg ha^{-1}, and grain yield 6300 kg ha^{-1}. Similarly, the 2.0 kg ha^{-1} treatment yielded 64.11 cm in plant height, 10.41 cm in spike length, 48 grains per spike, 45.69 g seed index, 6513 kg ha^{-1} biological yield, and 6189 kg ha^{-1} grain yield. The control group, which received no boron application, recorded the lowest values across all parameters, including 60.29 cm plant height, 9.49 cm spike length, 44 grains per spike, 41.57 g seed index, 5618 kg ha^{-1} biological yield, and 5565 kg ha^{-1} grain yield. The LSD value at $p < 0.05$ confirmed the statistical significance of the differences observed across treatments for all variables studied.

Further analysis of key growth attributes and economic returns revealed notable trends associated with increasing boron application. The number of tillers per plant improved progressively with higher boron doses, peaking at 4.8 tillers per plant in the 4.0 kg B ha^{-1} treatment compared to only 3.2 in the control. Days to heading decreased gradually, indicating faster crop development under higher boron availability, with the shortest time to heading (61 days) also observed in the 4.0 kg B ha^{-1} group. Similarly, root and shoot biomass were markedly enhanced by boron application, with the maximum root biomass (5.6 g) and shoot biomass (26.5 g) recorded at the highest boron level. In terms of economic viability, while the 4.0 kg B ha^{-1} treatment achieved the highest grain yield (6700 kg ha^{-1}) and gross returns (PKR 368,500), the 3.5 kg B ha^{-1} treatment provided slightly lower yield (6625 kg ha^{-1}) but higher net returns (PKR 362,750), suggesting it as the more cost-effective option. These findings emphasize the importance of balancing agronomic performance with input cost efficiency in optimizing boron fertilization strategies for wheat.

Table 1: Growth and yield parameters of wheat crop under different boron levels

B rate (kg B ha–1)	Plant height	Spike length (cm)	Grains spike ^{1}	Seed index (1000-grain weight, g)	Biological Yield (kg ha^{-1})	Grain Yield (kg ha^{-1})
Control	60.29 E	9.49E	44 D	41.57 D	5618 D	5565 D
2.0^{-1}	64.11 D	10.41 D	48 C	45.69 C	6513 C	6189 C
2.5	65.94 C	10.96C	49 C	46.50 C	6571 C	6300 C
3.0	70.58 B	13.48 B	53 B	48.56 B	7111 B	6466 B
3.5	73.81 A	15.44A	55 A	52.23 A	7487 A	6625 A
4.0	74.92 A	15.68A	56 A	52.69 A	7515 A	6700 A
LSD <0.05	1.24	0.3893	1.83	1.18	102.49	134.17

Table 2: Effect of Boron Application Rates on Key Growth Traits and Economic Returns in Wheat (Triticum aestivum L.)

B rate (kg B ha^{-1})	Tillers per Plant	Days to Heading	Root Biomass (g)	Shoot Biomass (g)	Grain Yield (kg ha^{-1})	Boron Cost (PKR)	Gross Returns (PKR)	Net Returns (PKR)
0	3.2	68	4.1	18.5	5565	0	306075	306075
2	3.8	66	4.6	21.2	6189	1500	340395	338895
2.5	4	65	4.8	22	6300	1875	346500	344625
3	4.4	63	5.2	24.6	6466	2250	355630	353380
3.5	4.7	62	5.5	26	6625	2625	364375	361750
4	4.8	61	5.6	26.5	6700	3000	368500	365500

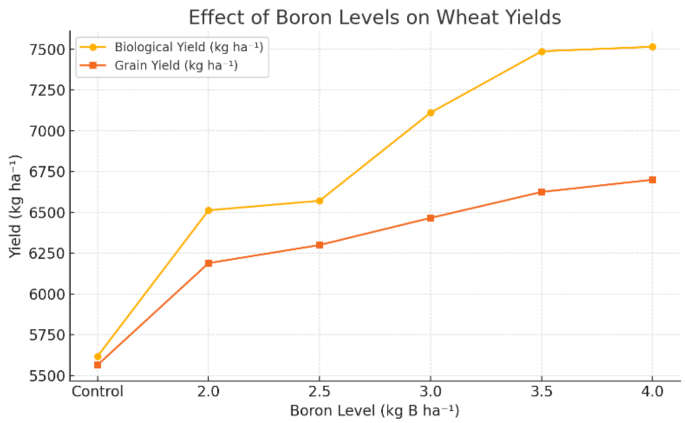

Figure 1 Effect of Boron Levels on Wheat Yields

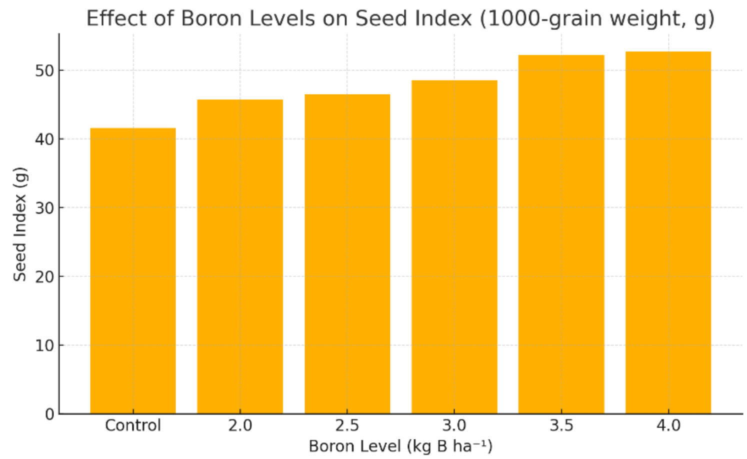

Figure 2 Effect of Boron Levels on Seed Index (1000-grain weight, g)

DISCUSSION

The findings of the present study underscore the significant influence of boron application on key agronomic traits and yield components of wheat, particularly under boron-deficient field conditions. Notably, the application of boron enhanced plant height, spike length, grain number per spike, seed index, and overall biological and grain yield. These outcomes corroborate earlier research where boron supply during the reproductive phase was shown to improve grain filling, reduce spikelet sterility, and increase the number of grains per spike—an effect directly linked to boron's essential role in pollen germination and fertilization processes during the booting stage (12). The higher demand for boron by male reproductive organs such as anthers highlights its critical involvement in successful grain setting, especially in boron-deficient soils (13,14). A clear upward trend was observed in 1000-grain weight with increased boron levels, reflecting the formation of healthier and more fully developed grains. This aligns with prior findings where boron application at key phenological stages significantly improved grain quality and weight metrics. These physiological improvements contributed to notable increases in yield, in some instances exceeding 30%, primarily due to improved spike fertility and reduced sterility (15). The beneficial effects of boron were also evident in root and shoot biomass, further indicating its systemic role in enhancing plant vigor and reproductive output (16).

Although some earlier studies suggested that boron might not consistently impact final grain yield despite improving intermediate traits such as seed weight and spike fertility, the results of this study demonstrated a statistically significant and agronomically relevant yield increase with boron application (17,18). However, yield benefits must be interpreted within the context of optimal dosage, as excessively high levels may risk toxicity and result in diminishing returns. The findings also support economic viability, as net returns were maximized at slightly lower boron rates (3.5 kg ha^{-1}), indicating the importance of cost-effective nutrient management strategies in wheat cultivation (19,20). Despite its strengths, the study had certain limitations. It was restricted to a single season and location, which may constrain the generalizability of the results to other agro-climatic zones. Moreover, although various physiological and yield-related parameters were recorded, additional markers such as chlorophyll content, photosynthetic efficiency, soil boron dynamics, and reproductive physiology indicators could provide a more comprehensive understanding of boron's mechanisms of action. The absence of long-term soil health monitoring and residual boron assessment also limits insight into sustainability concerns. Future research should expand to multi-location trials and consider the interactive effects of boron with other micronutrients and soil amendments. Investigating foliar versus soil applications at critical growth stages may also yield insights into stage-specific efficiency. Incorporating advanced tools such as remote sensing, plant tissue diagnostics, and economic modeling could further refine boron management recommendations (21). Nonetheless, the study contributes meaningfully to existing knowledge and emphasizes that site-specific boron application, tailored to both crop needs and economic feasibility, holds promise for improving wheat productivity in regions affected by micronutrient deficiencies.

CONCLUSION

The study concludes that boron supplementation plays a vital role in improving wheat growth, development, and yield-related attributes, particularly in soils prone to micronutrient deficiencies. Among the tested treatments, one specific application level emerged as the most agronomically and economically beneficial, enhancing productivity without triggering adverse effects associated with excess boron. These findings highlight the importance of targeted micronutrient management in sustainable wheat production, offering a practical approach to optimize yield while maintaining soil and crop health. The results provide valuable guidance for farmers and agronomists seeking to improve wheat performance under similar agro-climatic conditions.

AUTHOR CONTRIBUTION

Author	Contribution
Asra Memon	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Nighat Seema Soomoro	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Farheen Deeba Soomro	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Hajra Khan	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Asif Ali Kaleri*	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Javeria Tabbsum Talpur	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Ghazala Soomro	Contributed to study concept and Data collection Has given Final Approval of the version to be published
Muhid Hassan Soomro	Writing - Review & Editing, Assistance with Data Curation

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