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Effect of interactive nutrition of sulphur (S) and boron (B) on agronomic, physiological, and yield attributes of Cuìt glutinous rice (*Oryza sativa* var. *glutinosa*) in Quang Ngai

D. C. NGUYEN[1], T. L. NGUYEN[2,*], T. H. NGUYEN[3] AND D. T. NGUYEN[4]

[2]*Quy Nhon University*
170 An Duong Vuong St., Gia Lai, Vietnam
**(e-mail: nguyenthanhliem@qnu.edu.vn)*

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ABSTRACT

Low and unstable productivity of Cút glutinous rice in Quang Ngai is largely attributed to nutrient-deficient acidic soils and increasing heat stress during the reproductive stage. Identifying an optimum sulfur and boron nutrition strategy is therefore essential to improve grain yield, quality, and production sustainability. Based on this, the study was conducted over two consecutive Autumn–Winter paddy (2024-2025) in Nghia Giang commune, Quang Ngai province, Vietnam to evaluate the efficiency of combined sulphur (S) and boron (B) application on special Cút glutinous rice variety. A two-factor experiment was laid out in a Randomized Complete Block Design (RCBD) with four S levels (0, 15, 30, and 45 kg S/ha) and four B levels (0, 1.5, 3.0 and 4.5 kg B/ha) atop a basal fertilizer dose (5 tons manure + 90 N + 50 P_2O_5 + 60 K_2O/ha), replicated three times. Analysis of 12 agro-biological indicators revealed that the S × B interaction decisively influenced rice yield. While vegetative growth and grain dimensions remained relatively stable, yield components (panicle number, grain filling rate) and physiological parameters (CO_2 absorption) responded strongly to fertilizer treatments. The treatment with 30 kg S/ha combined with 4.5 kg B/ha proved most superior, maximizing the filled grain rate (88.8-92.7%) and actual yield (4.33-4.52 t/ha), which was 20-30% higher than the control. These results confirm the synergistic role of S and B in improving photosynthetic efficiency and pollination, providing a scientific basis for sustainable intensive cultivation of Cút glutinous rice variety.

Key words: Boron, Cút glutinous rice, sulphur, yield

INTRODUCTION

Glutinous rice (*Oryza sativa* var. *glutinosa*), specifically the special Cút glutinous rice variety in Quang Ngai, has long established its economic value and superior commercial quality due to its distinctive aroma and flavor (Tran and Nguyen, 2020). However, current agricultural practices indicate that the yield of this rice variety remains low and unstable. The root causes stem not only from traditional, experience-based farming practices but also from the immense pressure of adverse natural conditions and local soil degradation.

Climate monitoring data in the lower basins of the Tra Khuc and Ve Rivers (Quang Ngai) indicate an increase in extreme weather events. These include prolonged severe heatwaves with temperatures reaching 38-39°C, exacerbated by dry and hot Southwest winds (Quang Ngai Hydrometeorological Station, 2024). Furthermore, agrochemical analyses of intensive farming soils in this region have revealed critical nutritional "bottlenecks": the soil is highly acidic, with a pH_{KCl} ranging from 3.77 to 4.27, and is deficient in available nitrogen and potassium. In the context of intensive multicropping to adapt to climatic changes, the over-reliance on inorganic macronutrient fertilizers (N-P-K) while neglecting other essential elements has severely depleted the soil. This has led to a critical deficiency and imbalance of secondary

[1]Institute of Biotechnology, Hue University, 10 Nguyen Dinh Tu St., Hue, Vietnam.
[3]Pham Van Dong University, 509 Phan Dinh Phung St., Quang Ngai, Vietnam.
[4]University of Agriculture and Forestry, Hue University, 102 Phung Hung St., Hue, Vietnam.

macronutrients such as sulfur (S) and micronutrients such as boron (B).

The deficiency of S and B in degraded, acidic soils is a direct limiting factor for both the yield and quality of glutinous rice. Physiologically, sulfur is directly involved in photosynthesis and is an indispensable component for the synthesis of proteins and aroma compounds. It also enhances the rice plant's resilience against adverse environmental conditions (Zhao *et al.*, 2014). Meanwhile, boron plays a vital role during the reproductive stage: it improves pollen viability and facilitates pollination, grain setting, and carbohydrate transport (Shireen *et al.*, 2018). The timely supplementation of boron is a key solution to mitigate the rate of unfilled and discolored grains (Rehman *et al.*, 2012), a significant physiological risk when rice flowers during the intense heatwaves typical of Central Vietnam.

Driven by the urgent demands of agricultural production and grounded in the theoretical foundations of plant physiology, this study was conducted to determine the optimal combination of sulfur (S) and boron (B). Through a comprehensive evaluation of 12 agronomic and physiological indicators, the findings of this research will provide a robust scientific basis for adjusting nutrient management protocols. This will not only help maximize yield potential but also contribute to the sustainable development of The Cút glutinous rice, a traditional specialty of Quang Ngai Province, amid the challenges posed by climate change.

MATERIALS AND METHODS

Materials and Location

The field experiments were carried out using the Cút glutinous rice variety (*Oryza sativa* var. *glutinosa*). The primary fertilizer sources utilized in this study included ammonium sulfate (containing 21% N and 24% S), boric acid (containing 17% B), urea (46% N), fused magnesium phosphate (17% P_2O_5), potassium chloride (60% K_2O), and traditional farmyard manure. The research was conducted under the technical management and joint supervision of the Institute of Biotechnology (Hue University) and Quy Nhon University at an experimental field located in Nghia Giang commune, Quang Ngai province, Viet Nam (15°07′42.7″N - 108°44′10.1″E) (Fig. 1). The experimental trial spanned two consecutive Autumn-Winter seasons, specifically from July to November 2024 and from July to November 2025.

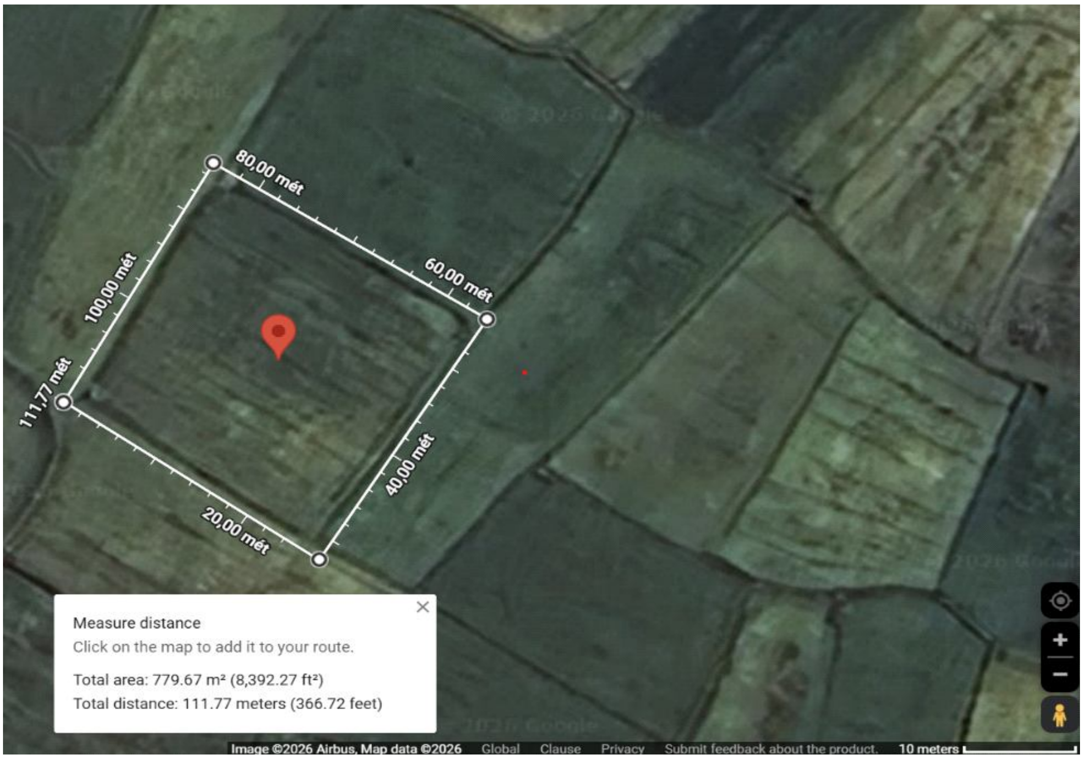

Fig. 1. Location of the experimental field in Nghia Giang, Quang Ngai, Vietnam.

Experimental Design and Crop Management

The field trial was laid out in a 4 × 4 Factorial Randomized Complete Block Design (RCBD) with three replications (Fig. 2), comprising a total of 48 experimental plots with an individual plot size of 5 m_2. The treatments consisted of four sulfur (S) levels (0, 15, 30, and 45 kg/ha) and four boron (B) levels (0, 1.5, 3.0, and 4.5 kg/ha) applied using $(NH4)_2SO_4$ and $B(OH)_3$ as nutrient sources. All treatments received a uniform basal fertilizer dose consisting of 5 t/ha of manure, 90 kg N/ha, 50 kg /ha, and 60 kg /ha. A distance of 50 cm was maintained between adjacent experimental plots, and a 2 m isolation buffer zone was established around the borders. Rice seedlings were transplanted at a density of 25 hills/ with a precise plant spacing of 20 cm 20 cm.

Regarding the schedule of fertilizer application, the basal dose included 100% of the manure, 100% of the P, 30% of the N, and 20% of the K. Top-dressing 1 was applied during early vegetative growth with 50% N, 30% K, and 50% S. Top-dressing 2 was performed at the panicle initiation stage, providing 20% N, 50% K, 50% S, and a 50% B foliar spray. The remaining 50% B foliar spray was applied during Top-dressing 3 at the heading stage. Other standard local intensive rice cultivation practices, including scheduled irrigation, pest management, and disease control protocols, were applied uniformly across all experimental treatments.

Data Collection

To comprehensively assess the growth, productivity, and grain quality of rice under different Sulphur (S) and Boron (B) fertilizer treatments, 12 agro-biological indicators were measured throughout the experimental period. Growth and morphological traits included plant height (cm), leaf area index (LAI), and the number of effective tillers/hills. Yield components were evaluated through the number of panicles/m^2 (panicles/m^2), the number of grains per panicle (including total grains and filled grains per panicle), 1000-grain weight (g), and grain filling rate (%). Yield performance was determined by estimating theoretical yield (t/ha), actual yield (t/ha), and harvest index (HI). In addition, physiological and grain quality attributes were assessed through accumulated CO sequestration (t/ha) and the length-to-width (L/W) ratio of milled grains. These parameters collectively provided a comprehensive evaluation of crop growth, yield formation, physiological performance, and grain quality in response to Sulphur and Boron fertilization.

Evaluation Methods

Methods for investigating plant canopy, tillers, yield components, yield, and major

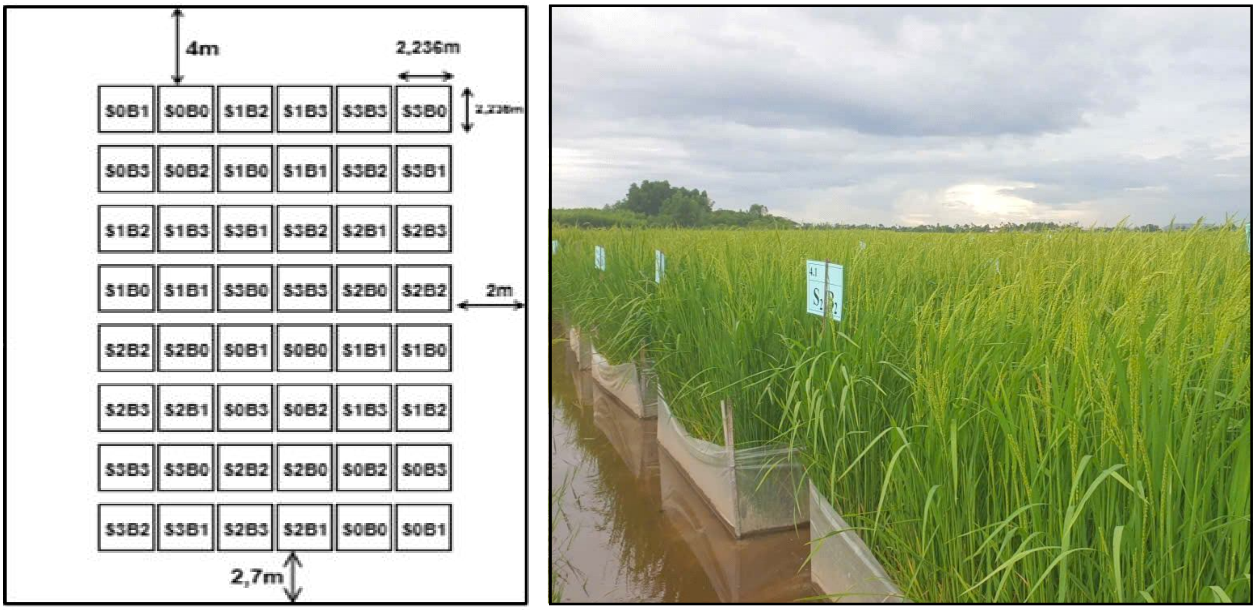

Fig. 2. Experimental layout diagram. Experimental plots within each block were arranged in a Randomized Complete Block Design (RCBD) to ensure objectivity.

pests/diseases were applied according to TCVN-13381-1:2023 (Ministry of Science and Technology, 2023). The Leaf Area Index (LAI) was estimated by determining the area of the functional leaf (2nd leaf from the top) and the number of green leaves on the main stem at the heading stage. Leaf area was calculated according to Yoshida (1981) with an adjustment coefficient , under the hypothesis that the functional leaf area has a strong positive correlation with the total whole-plant leaf area during the heading stage.

Regarding yield components, panicles/m², filled grains/panicle, and 1000-grain weight were collected and measured as per TCVN 13381-1:2023. From these data, theoretical grain yield (TGY) was calculated using the equation:

$$\text{TGY (t/ha)} = \frac{\text{(Panicles/m}^2 \times \text{Grains/panicle} \times \text{Filled grain rate} \times \text{Weight of 1000 grains (g)}}{10^5}$$

For the actual grain yield (t/ha), rice was harvested from each experimental plot, sun-dried, weighed for dry grain mass, and then converted to actual yield per hectare. Biological yield (t/ha) was determined as the actual grain yield divided by the Harvest Index (HI), where HI equals grain mass per plant divided by total plant mass. Additionally, the absorption amount (t/ha/season) was calculated as:

$$CO_2 = \frac{C \times 44}{12}$$

Where, represents the accumulated carbon content determined by:

Data Analysis

Data were analyzed using Statistix 8.0 software. Differences among means were compared using Tukey's HSD test at a significance level of alpha = 0.05.

RESULTS AND DISCUSSION

Effect of Sulphur and Boron on Vegetative Growth

Statistical results indicate that vegetative growth factors experienced variations between the two years.

The statistical analysis revealed that vegetative morphological indicators such as plant height were relatively stable, with no statistically significant differences observed among treatments in both seasons ($P > 0.05$). Average plant height reached 162.6 cm (in 2024) and 155.2 cm (in 2025). This proves that plant height is a stable genetic trait, minimally affected by the tested S and B dosages. The experimental levels applied of S and B did not induce excessive elongation or lodging, ensuring safety for commercial production (Table 1).

However, concerning the plant canopy, the S × B interaction clearly manifested in the Leaf Area Index (LAI) and leaf area. In the 2025 season, the treatment supplemented with a high level of sulphur (S_3) combined with boron helped maintain sustained green foliage, with the LAI peaking (5.8), significantly different from the control. This result aligns with the findings of Shivay *et al.* (2016), affirming the role of sulphur in maintaining chlorophyll content and extending flag leaf longevity.

Statistical analysis across two seasons demonstrated that the tillering capacity of the Cút glutinous rice variety depends not only on genetic characteristics but is also strongly influenced by the nutritional interaction between sulphur (S) and boron (B), especially evident in the 2025 season at a significance level of $P < 0.01$. Specifically, the S_2B_3 combination formula recorded optimal effective tiller density, showing a significant difference compared to single-application treatments or the control. Physiologically, this increase can be explained through a synergistic mechanism: Sulphur (S) plays an essential role in synthesizing sulphur-containing amino acids (such as Cysteine and Methionine) and activating enzyme systems involved in nitrogen metabolism. This promotes cell division in meristematic tissues, enabling vigorous and concentrated tillering. Meanwhile, Boron (B), although typically known for its reproductive role, actively participates in sugar transport and cell wall synthesis during the vegetative stage. This makes the newly formed tillers robust, enhancing their ability to compete for light and nutrients to develop into effective tillers.

Table 1. Effect of S and B dosage on plant height, leaf area index (LAI), and number of effective tillers

S Level (kg/ha)	B Level (kg/ha)	Autumn-Winter Season 2024			Autumn-Winter Season 2025		
		Plant height (cm)	LAI	Effective tillers/ hill	Plant height (cm)	LAI	Effective tillers/ hill
0	0.0	166.08 [a]	6.39 [a]	7.47 [a]	158.05 [a]	4.76 [a]	6.13 [b]
	1.5	162.67 [a]	5.91 [ab]	7.60 [a]	157.06 [a]	4.64 [a]	6.67 [ab]
	3.0	165.33 [a]	4.01 [abc]	6.33 [a]	151.09 [a]	4.61 [a]	7.13 [ab]
	4.5	162.47 [a]	4.52 [abc]	7.00 [a]	150.73 [a]	4.60 [a]	7.13 [ab]
15	0.0	164.67 [a]	4.50 [abc]	6.67 [a]	163.28 [a]	5.10 [a]	6.87 [ab]
	1.5	169.27 [a]	4.54 [abc]	7.33 [a]	156.06 [a]	3.97 [a]	6.13 [b]
	3.0	161.13 [a]	4.39 [abc]	6.00 [a]	155.86 [a]	5.32 [a]	6.67 [ab]
	4.5	159.66 [a]	4.51 [abc]	6.20 [a]	156.24 [a]	5.67 [a]	7.27 [ab]
30	0.0	160.33 [a]	3.95 [bc]	6.53 [a]	155.62 [a]	4.41 [a]	7.33 [ab]
	1.5	168.40 [a]	5.19 [abc]	7.47 [a]	154.22 [a]	6.11 [a]	7.33 [ab]
	3.0	161.58 [a]	3.16 [c]	5.80 [a]	152.17 [a]	4.44 [a]	6.60 [ab]
	4.5	159.45 [a]	5.90 [ab]	7.07 [a]	156.29 [a]	5.26 [a]	8.13 [a]
45	0.0	162.53 [a]	5.64 [ab]	7.53 [a]	152.07 [a]	6.31 [a]	7.40 [ab]
	1.5	160.94 [a]	4.63 [abc]	6.47 [a]	155.79 [a]	6.06 [a]	8.07 [a]
	3.0	158.07 [a]	5.12 [abc]	6.47 [a]	157.67 [a]	6.29 [a]	7.80 [ab]
	4.5	159.47 [a]	4.33 [abc]	6.27 [a]	150.58 [a]	4.56 [a]	6.67 [ab]
HSD_S	6.20	0.87	0.85	6.44	1.01	0.63	
HSD_B	6.20	0.87	0.85	6.44	1.01	0.63	
HSD_{SxB}	16.97	2.39	2.33	17.63	2.78	1.73	

Values in the same column with different letters indicate statistical significance at P <0.05; LAI: Leaf Area Index; HSD: Tukey's Honestly Significant Difference; HSD_S: HSD for Sulphur; HSD_B: HSD for Boron; HSD_{SxB}: HSD for Sulphur and Boron interaction.

Effect of Sulphur and Boron on Yield Components

This group of indicators experienced the strongest impact from the combined fertilizer treatments.

The number of panicles per square meter is the most fundamental yield-forming component, directly reflecting the crop's ability to transition from vegetative growth (tillering) to reproductive growth (panicle initiation). The research results showed that the interaction between S and B had significant statistical importance (P <0.01 in the 2025 season), with the S_2B_3 treatment achieving the highest panicle density (203 panicles/m²), outperforming the control (153 panicles/m²) by 25% (Table 2).

Mechanistically, this sudden increase is not random but the result of a physiological synergistic effect. Sulphur plays a critical role in increasing nitrogen use efficiency. When sufficiently supplied with S (30 kg S/ha), protein and chlorophyll synthesis occur robustly, helping the rice plant maintain the survival of young tillers through the harsh biological competition phase (maximum tillering stage). Concurrently, boron (4.5 kg B/ha) assumes the function of transporting sugars and carbohydrates from leaves to apical meristems, ensuring the energy source to nourish these tillers to develop into effective panicles rather than degenerating into unproductive ones. Thus, the S_2B_3 formula in this study established an optimal nutritional balance, enabling the Cút glutinous rice variety to maximise its inherent tillering potential.

Observations across two seasons showed that the number of grains per panicle of the Cút variety fluctuated between 139 and 163 grains/panicle. Specifically, in the S_2B_3 treatment, the grain count reached 163.07 grains (2024) and 147.67 grains (2025), higher than the control (153.73 and 139.40 grains); however, this difference lacked statistical significance (*P >0.05*). The supplementation of S and B in this experiment did not seem to exert a large enough impact to alter the panicle structure of the Cút glutinous rice variety.

Similar to the grains per panicle indicator, the P1000 parameter maintained high stability, ranging from 23.0 to 26.0 g with no statistically significant differences (*P >0.05*). The mechanism behind this phenomenon lies in the anatomical structure of the rice grain. The maximum size and weight of a grain are determined by the width

Table 2. Effect of S and B dosage on panicles/m², grains/panicle, and 1000-grain weight

S Level (kg/ha)	B Level (kg/ha)	Autumn-Winter Season 2024			Autumn-Winter Season 2025		
		Panicles/ m²	Grains/ panicle	1000-grain weight (g)	Panicles/ m²	Grains/ panicle	1000-grain weight (g)
0	0.0	186.67 ^{a}	153.73 ^{a}	23.56 ^{a}	153.33 ^{b}	139.40 ^{a}	26.50 ^{a}
	1.5	190.00 ^{a}	128.53 ^{a}	25.32 ^{a}	166.67 ^{ab}	144.13 ^{a}	25.52 ^{a}
	3.0	158.33 ^{a}	159.13 ^{a}	24.32 ^{a}	178.33 ^{ab}	157.47 ^{a}	24.37 ^{a}
	4.5	175.00 ^{a}	134.80 ^{a}	25.18 ^{a}	178.33 ^{ab}	154.80 ^{a}	23.86 ^{a}
15	0.0	166.67 ^{a}	158.20 ^{a}	24.52 ^{a}	171.67 ^{ab}	134.47 ^{a}	24.77 ^{a}
	1.5	183.33 ^{a}	133.60 ^{a}	26.02 ^{a}	153.33 ^{b}	148.13 ^{a}	25.14 ^{a}
	3.0	150.00 ^{a}	162.53 ^{a}	25.45 ^{a}	166.67 ^{ab}	131.93 ^{a}	25.73 ^{a}
	4.5	155.00 ^{a}	154.33 ^{a}	25.63 ^{a}	181.67 ^{ab}	136.33 ^{a}	24.76 ^{a}
30	0.0	163.33 ^{a}	142.27 ^{a}	25.40 ^{a}	183.33 ^{ab}	137.73 ^{a}	24.51 ^{a}
	1.5	186.67 ^{a}	131.80 ^{a}	24.59 ^{a}	183.33 ^{ab}	141.93 ^{a}	24.57 ^{a}
	3.0	145.00 ^{a}	140.27 ^{a}	25.28 ^{a}	165.00 ^{ab}	142.53 ^{a}	25.73 ^{a}
	4.5	176.67 ^{a}	163.07 ^{a}	23.32 ^{a}	203.33 ^{a}	147.67 ^{a}	23.15 ^{a}
45	0.0	188.33 ^{a}	137.67 ^{a}	24.72 ^{a}	185.00 ^{ab}	143.40 ^{a}	23.51 ^{a}
	1.5	161.67 ^{a}	164.93 ^{a}	23.46 ^{a}	201.67 ^{a}	135.47 ^{a}	24.64 ^{a}
	3.0	161.67 ^{a}	170.07 ^{a}	23.98 ^{a}	195.00 ^{ab}	141.73 ^{a}	23.55 ^{a}
	4.5	156.67 ^{a}	142.33 ^{a}	26.76 ^{a}	166.67 ^{ab}	145.93 ^{a}	25.27 ^{a}
HSD_S	21.31	17.12	1.60	15.83	13.55	1.48	
HSD_B	21.31	17.12	1.60	15.83	13.55	1.48	
HSD_{SxB}	58.37	46.89	4.38	43.36	37.12	4.05	

Values in the same column with different letters indicate statistical significance at P <0.05; P1000: 1000-grain weight; HSD: Tukey's Honestly Significant Difference; HSD_S: HSD for Sulphur; HSD_B: HSD for Boron; HSD_{SxB}: HSD for Sulphur and Boron interaction.

of the hull (lemma and palea), which is permanently formed right before the heading stage. The role of sulphur and boron in this study mainly focused on filling dry matter inside the hull rather than expanding the hull size beyond the variety's genetic limits. From a commercial perspective, the stability of P1000 in this study is a positive signal, showing that intensive farming using the S_2B_3 formula increases actual yield while preserving the grain size and characteristic morphology of the Cút variety, thereby maintaining the commercial quality of this local speciality rice.

Effect of Sulphur and Boron on Yield and Stability

Actual yield is the comprehensive outcome of all yield components.

Theoretical yield reflects the maximum potential of the variety under experimental conditions based on its yield components. Results showed that the theoretical yield of the Cút glutinous rice variety peaked at 6.43 t/ha in the S_2B_3 treatment (2025 season), significantly surpassing the control (4.69 t/ha) (Table 3). This result is consistent with Yoshida's (1981) rice yield model, affirming that theoretical yield is limited by sink capacity. In this study, the S_2B_3 application expanded the sink capacity of the Cút variety to its maximum genotype potential, approaching the theoretical yield of short-duration high-yielding rice varieties, which typically reach 7-8 t/ha according to the Cuu Long Delta Rice Research Institute (2020).

Actual yield demonstrated the clearest difference in economic efficiency. The S_2B_3 treatment reached 4.52 t/ha, whereas nutrient-deficient treatments only yielded 3.02-3.32 t/ha. A notable point is the gap between theoretical and actual yield. In the control formula (S_0B_0), this gap was massive (dropping from 4.69 tons to 3.02 tons, a loss of ~36%), primarily due to a high unfilled grain rate. In contrast, in the S_2B_3 formula, this gap was significantly narrowed (a loss of only ~29%). Achieving a yield of > 4 t/ha for the Cút glutinous rice variety is a major step forward. Compared to reports from the Quang Ngai Department of Agriculture and Rural Development (2023), the mass production yield of local glutinous rice only ranges from 4.0 to 4.2 t/ha.

The harvest index (the ratio between economic yield and biological yield) in the experiment fluctuated stably between 0.44 and 0.46, with no major discrepancies among

Table 3. Effect of S and B dosage on theoretical yield, actual yield, and harvest index

S Level (kg/ha)	B Level (kg/ha)	Autumn-Winter Season 2024			Autumn-Winter Season 2025		
		Theoretical yield (t/ha)	Actual yield (t/ha)	Harvest Index (HI)	Theoretical yield (t/ha)	Actual yield (t/ha)	Harvest Index (HI)
0	0.0	4.96 [ab]	3.32 [ab]	0.46 [ab]	4.69 [b]	3.02 [b]	0.47 [a]
	1.5	5.09 [ab]	3.22 [ab]	0.46 [ab]	5.52 [ab]	3.78 [ab]	0.46 [a]
	3.0	4.71 [ab]	3.21 [ab]	0.49 [a]	6.18 [ab]	4.33 [ab]	0.46 [a]
	4.5	4.67 [ab]	3.31 [ab]	0.43 [ab]	5.95 [ab]	4.25 [ab]	0.46 [a]
15	0.0	5.07 [ab]	3.32 [ab]	0.44 [ab]	5.19 [ab]	3.28 [ab]	0.44 [a]
	1.5	5.40 [ab]	3.73 [ab]	0.46 [ab]	5.18 [ab]	3.67 [ab]	0.47 [a]
	3.0	4.90 [ab]	3.11 [ab]	0.45 [ab]	4.59 [b]	3.12 [ab]	0.45 [a]
	4.5	5.01 [ab]	3.33 [ab]	0.42 [b]	5.26 [ab]	3.62 [ab]	0.42 [a]
30	0.0	4.86 [ab]	2.95 [ab]	0.45 [ab]	5.62 [ab]	3.68 [ab]	0.46 [a]
	1.5	4.77 [ab]	3.03 [ab]	0.46 [ab]	5.70 [ab]	3.96 [ab]	0.46 [a]
	3.0	4.34 [b]	2.60 [b]	0.46 [ab]	5.19 [ab]	3.31 [ab]	0.44 [a]
	4.5	5.96 [a]	4.33 [a]	0.40 [b]	6.43 [a]	4.52 [a]	0.41 [a]
45	0.0	5.61 [ab]	3.48 [ab]	0.43 [ab]	5.70 [ab]	3.87 [ab]	0.42 [a]
	1.5	4.88 [ab]	3.24 [ab]	0.44 [ab]	6.02 [ab]	4.15 [ab]	0.43 [a]
	3.0	4.88 [ab]	3.17 [ab]	0.43 [ab]	5.77 [ab]	3.94 [ab]	0.43 [a]
	4.5	4.98 [ab]	3.48 [ab]	0.41 [b]	5.64 [ab]	3.63 [ab]	0.40 [a]
HSD_S	0.52	0.52	0.03	0.58	0.54	0.03	
HSD_B	0.52	0.52	0.03	0.58	0.54	0.03	
HSD_{SxB}	1.42	1.42	0.07	1.59	1.49	0.08	

Values in the same column with different letters indicate statistical significance at $P < 0.05$; HI: Harvest Index; HSD: Tukey's Honestly Significant Difference; HSD_S: HSD for Sulphur; HSD_B: HSD for Boron; HSD_{SxB}: HSD for Sulphur and Boron interaction.

treatments. According to Donald & Hamblin (1976), the pioneers of the HI concept, traditional rice varieties usually have a low HI (< 0.4), while improved (high-yielding) varieties have an HI ranging from 0.45-0.55. The Cút variety, achieving an HI of ~0.46 in this study, indicates that the variety has been well-restored and responds positively to fertilisers. This result aligns with Fageria's (2007) research, suggesting that balanced fertilisation (NPK + secondary/micronutrients) optimises assimilate partitioning from stems and leaves to grains, preventing the HI from dropping even when total biomass increases.

In summary, the S_2B_3 interaction not only elevates sink capacity (reflected by the theoretical yield reaching 6.43 t/ha) but also optimises the grain-filling efficiency (reflected by narrowing the actual yield gap). Particularly, maintaining a stable HI of 0.46 confirms that the increase in actual yield (reaching 4.52 t/ha) is the outcome of a balanced metabolic process, where sulphur secures the photosynthetic source and boron ensures smooth assimilate transport to the grain. This constitutes a solid scientific foundation for recommending this formula in commercial production.

Effect of Sulphur and Boron on Physiological Efficiency and Grain Quality

The accumulated CO_2 indicator is a direct consequence of biological yield. According to the principles of photosynthesis, to produce 1 ton of dry matter (biomass), a rice plant needs to absorb approximately 1.68 tons of CO, from the atmosphere.

Data in Table 4 reveal a massive difference in CO_2 absorption capacity among treatments. Specifically, in the 2025 season, the S_2B_3 treatment achieved a record absorption of 18.78 t/ha, categorised in group A (highest), while the control treatment (S_0B_0) only achieved 10.77 t/ha (group B). This outstanding increase (1.7 times higher than the control) reflects the efficiency of the S-B interaction on the photosynthetic apparatus. According to Hairiah's calculation principles (Hairiah *et al.*, 2011), the larger the biomass, the higher the amount of CO, fixed from the atmosphere. These results prove that a Cút rice field intensively cultivated with S_2B_3 operates as an effective carbon sink, aligning with the trend of low-emission rice production and enhanced greenhouse gas absorption.

Table 4. Effect of S and B dosage on accumulated CO_2 content, filled grain rate, and grain dimensions

S Level (kg/ha)	B Level (kg/ha)	Autumn-Winter Season 2024			Autumn-Winter Season 2025		
		Accumulated CO, (t/ha)	Filled rate (%)	L/W ratio of milled grain	Accumulated CO, (t/ha)	Filled rate (%)	L/W ratio of milled grain
0	0.0	12.31 ^{ab}	73.82 ^{d}	1.70 ^{a}	10.77 ^{b}	83.06 ^{d}	1.70 ^{a}
	1.5	11.80 ^{b}	83.25 ^{abc}	1.77 ^{a}	13.97 ^{ab}	90.75 ^{ab}	1.60 ^{a}
	3.0	11.00 ^{b}	77.46 ^{cd}	1.70 ^{a}	15.88 ^{ab}	90.55 ^{abc}	1.64 ^{a}
	4.5	13.06 ^{ab}	79.05 ^{bcd}	1.73 ^{a}	15.70 ^{ab}	90.94 ^{ab}	1.61 ^{a}
15	0.0	12.71 ^{ab}	78.73 ^{bcd}	1.66 ^{a}	12.60 ^{b}	90.88 ^{ab}	1.69 ^{a}
	1.5	13.84 ^{ab}	85.16 ^{ab}	1.68 ^{a}	13.27 ^{ab}	90.74 ^{ab}	1.65 ^{a}
	3.0	11.70 ^{b}	79.61 ^{bcd}	1.66 ^{a}	11.63 ^{b}	81.58 ^{d}	1.65 ^{a}
	4.5	13.54 ^{ab}	82.22 ^{abc}	1.62 ^{a}	14.33 ^{ab}	86.29 ^{bcd}	1.68 ^{a}
30	0.0	11.22 ^{b}	82.95 ^{abc}	1.67 ^{a}	13.64 ^{ab}	91.25 ^{a}	1.70 ^{a}
	1.5	11.04 ^{b}	79.86 ^{bcd}	1.73 ^{a}	14.70 ^{ab}	89.66 ^{abc}	1.65 ^{a}
	3.0	9.56 ^{b}	85.11 ^{ab}	1.68 ^{a}	12.65 ^{b}	85.86 ^{cd}	1.64 ^{a}
	4.5	18.28 ^{a}	88.87 ^{a}	1.65 ^{a}	18.78 ^{a}	92.76 ^{a}	1.64 ^{a}
45	0.0	13.57 ^{ab}	88.36 ^{a}	1.72 ^{a}	15.56 ^{ab}	91.66 ^{a}	1.65 ^{a}
	1.5	12.50 ^{ab}	78.12 ^{bcd}	1.65 ^{a}	16.22 ^{ab}	90.03 ^{abc}	1.68 ^{a}
	3.0	12.32 ^{ab}	74.53 ^{d}	1.72 ^{a}	15.56 ^{ab}	88.85 ^{abc}	1.65 ^{a}
	4.5	14.28 ^{ab}	83.99 ^{abc}	1.70 ^{a}	15.27 ^{ab}	92.15 ^{a}	1.63 ^{a}
HSD_S	2.23	2.70	0.06	2.20	1.77	0.07	
HSD_B	2.23	2.70	0.06	2.20	1.77	0.07	
HSD_{SxB}	6.10	7.41	0.18	6.04	4.85	0.18	

Values in the same column with different letters indicate statistical significance at P <0.05; L/W ratio: Length/Width ratio; HSD: Tukey's Honestly Significant Difference; HSD_S: HSD for Sulphur; HSD_B: HSD for Boron; HSD_{SxB}: HSD for Sulphur and Boron interaction.

If CO_2 is the input, the filled grain rate is the ultimate measure of efficiency. Data in Table 4 demonstrate the spectacular breakthrough of the S_2B_3 treatment, with the filled grain rate reaching up to 92.76% (2025) and 88.87% (2024), overwhelmingly outperforming the control (73-78%). This result is completely consistent with studies by Lordkaew *et al.* (2013) and Rehman *et al.* (2014) on rice. These authors demonstrated that boron deficiency causes male sterility, leading to poor pollen germination and subsequently high unfilled grain rates. The addition of B3 (4.5 kg B/ha) completely overcame the pollination problem, successfully converting the abundant dry matter from stems and leaves into the grain. A rate of 92.76% is a highly impressive figure for local glutinous varieties (which typically suffer from a high unfilled rate >20%), confirming that this formula has resolved the most critical physiological bottleneck of the Cút variety.

While factors determining grain density, such as the filled grain rate, fluctuated strongly upwards, structural parameters like rice grain dimensions (length, width) and milled grain dimensions exhibited absolute stability. Specifically, in the optimal S_2B_3 treatment, despite the actual yield reaching a record 4.52 t/ha, the milled grain length remained at 4.78 mm and the width at 2.92 mm, showing no statistical difference compared to the control (*P >0.05*). The length/width ratio of the grain was stable within the range of 1.64-1.7, characterising the typical round shape of local glutinous rice.

From an agronomic and commercial perspective, this non-significant difference carries much greater value than merely an increase in size. It affirms the genetic stability of the Cút glutinous rice variety and proves that the S_2B_3 fertiliser formula boosts yield fundamentally (by increasing filled rates and reducing empty grains) without causing hybridisation or morphological distortion of the product. This conforms with the viewpoint of Lang and Bui (2011) on genetics and breeding, asserting that maintaining grain shape is vital to preserving the commercial standards of speciality rice varieties. Thus, the S-B nutritional solution succeeded in solving the conflict between yield and quality, helping farmers increase their income through higher yields while simultaneously protecting the signature brand of the round, aromatic, and Cút glutinous rice grain in the market.

CONCLUSION

In conclusion, the interactive nutrition of sulphur (S) and boron (B) significantly improves the tillering capacity, leaf area index, and yield attributes of Cút glutinous rice in Quang Ngai. The combined application of 30 kg S/ha and foliar spraying of 4.5 kg B/ha (S_2B_3) is the most effective protocol, maximizing effective panicles, reducing grain emptiness, and increasing actual yield by 20-30% compared to the control. This balanced fertilisation approach also enhances environmental efficiency via elevated CO_2 mitigation while successfully preserving the genetic grain morphology and commercial characteristics of this specialty rice variety. Future lines of research should focus on assessing the long-term economic returns of this nutrient strategy across diverse soil profiles in the region and evaluating its efficacy under varying climate change scenarios.

RECOMMENDATIONS

It is recommended to apply a balanced fertilization protocol using the formula 30 kg S/ha + 4.5 kg B/ha (combining basal soil application and foliar spraying during the panicle initiation-heading stage) in centralized Cút glutinous rice production zones in Quang Ngai to elevate both crop yield and economic efficiency.

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