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## Effect of micronutrients on growth, yield, and nutrient uptake of rice

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### Abstract

Micronutrients, though required in small amounts, are essential for crop growth and development. A pot experiment was performed to evaluate the effect of selected micronutrients, including zinc (Zn), copper (Cu), manganese (Mn), ferrous (Fe), and boron (B) on the growth and yield of rice (BRRI dhan92). The study was laid out in a Randomized Complete Design (CRD) with three replications. There were altogether eight treatment combinations, viz. T<sub>1</sub> = control (without fertilizer), T<sub>2</sub> = PKS (–N), T<sub>3</sub> = NPKS, T<sub>4</sub> = NPKS+Zn, T<sub>5</sub> = NPKS+Zn+Cu, T<sub>6</sub> = NPKS+Zn+Cu+Mn, T<sub>7</sub> = NPKS+Zn+Cu+Mn+F and T<sub>8</sub> = NPKS+Zn+Cu+Mn+F+B. The findings showed that treatment T<sub>8</sub> produced the tallest plants (60.05 cm and 84.22 cm at 30 and 50 DAT, respectively), the highest number of tillers (28.33 at harvest), and the highest SPAD values (43.36 and 48.56 at 30 and 50 DAT, respectively) compared with treatment T<sub>3</sub> alone. On the other hand, the treatment of T<sub>8</sub> gave the significantly highest grain yield (93.26 g hill<sup>–1</sup>), straw yield (47.32 g hill<sup>–1</sup>), panicle number hill<sup>–1</sup> (25.00), and the lowest sterility percentage (18.38) compared to T<sub>3</sub> alone. Foliar application of micronutrients did not influence 1000-grain weight. Treatment T<sub>8</sub> yielded the highest increases in grain and straw yields of 21.19% and 23.68%, respectively, over T<sub>3</sub>. The treatment T<sub>8</sub> maintained higher N, P, K, Zn, Cu, Mn, Fe, and B uptake in rice grain and straw. In conclusion, the Zn and Zn+Cu+Mn+F+B micronutrient combinations, along with NPKS, were found to be the best for achieving maximum growth and yield in boro rice.

**Keywords:** Micronutrients, rice, yield, growth, zinc, copper, manganese, ferrous, boron

### Introduction

Rice (*Oryza sativa* L.) is a major cereal crop worldwide, grown across diverse climatic regions (Abd El-Hakim *et al.*, 2022) <sup>[1]</sup>, and consumed by over 50% of the global population (Shaheen *et al.*, 2022) <sup>[43]</sup>. Rice is an inadequate source of zinc, copper, and other micronutrients (Fakharzadeh *et al.*, 2020) <sup>[18]</sup>.

Zinc (Zn) is an important element necessary for living organisms, playing a crucial role in normal physiological processes related to growth and development (Fageria *et al.*, 2002; Stanton *et al.*, 2022; Wu *et al.*, 2022) <sup>[17, 45, 52]</sup>. Moreover, Zn is integral to various plant metabolic processes, including enzyme activity, photosynthesis, chlorophyll synthesis, and other biochemical functions (Arif *et al.*, 2016; Grüngreiff *et al.*, 2020) <sup>[5, 24]</sup>. Zn modifies stomatal conductance and contributes to cellular protection against the detrimental effects of reactive oxygen species (Ghazi *et al.*, 2022) <sup>[21]</sup>. Copper (Cu) is an essential nutrient that influences physiological processes, mostly through Cu-containing proteins, which are vital for plant functions such as photosynthesis and mitochondrial respiration (Yruela, 2009) <sup>[54]</sup>. A copper deficiency in soil impairs rice plant metabolism, particularly photosynthesis and respiration. Manganese (Mn) functions in plant physiology as an enzyme activator and a catalyst in the photolytic cleavage of water molecules during photosynthesis (Gardner *et al.*, 1985; Humphries, 2006; Aref, 2012) <sup>[20, 29, 4]</sup>. Mn regulates chlorophyll synthesis, and its presence is crucial in Photosystem II (Diedrick, 2010) <sup>[14]</sup>. However, excess manganese is detrimental to most plants (Millaleo *et al.*, 2010) <sup>[37]</sup>. Both insufficient and excessive manganese inhibit plant growth (Dube *et al.*, 2002) <sup>[16]</sup>. Manganese stress elevates peroxidase activity associated with respiration in leaves and inhibits development (Dube *et al.*, 2001) <sup>[15]</sup>.

Iron (Fe) is a vital element for plants, serving as a cofactor for around 140 enzymes that facilitate distinct metabolic activities. It possesses low availability and mobility characteristics (Corey, 2006) [12]. Boron (B), a non-metal micronutrient, is crucial for the proper growth and development of plants, including rice, as first documented by Warington in 1933 [49] and later confirmed by Gupta in 1979 [25]. It is crucial for glucose metabolism, translocation, cell wall formation, and RNA metabolism (Herrera-Rodriguez *et al.*, 2010) [26]. Boron is essential for pollen tube growth, as it stimulates plasma membrane function, anther development, floret fertility, and seed formation (Wang *et al.*, 2003; Oosterhuis, 2001) [48, 38]. Inadequate levels of soil-borne boron diminish agricultural output, compromise grain quality, and increase crops' vulnerability to diseases (Goldbach *et al.*, 2007) [22]. Boron requirements differ among plant species (Bell, 1997) [7] and are influenced by factors like soil type (calcareousness/alkalinity), soil moisture, pH, boron concentration, soil organic matter, and plant species (Welch *et al.*, 1991) [51].

Consequently, adequate micronutrient nutrition is crucial for enhancing rice growth and yield. Typically, farmers utilize chemical fertilizers to supply nitrogen, phosphorus, and potassium for rice cultivation, but seldom incorporate micronutrients such as zinc, copper, manganese, iron, and boron. This has led to a decrease in soil micronutrient availability. Consequently, the crop's growth and yield may be negatively affected. Nevertheless, limited research has been undertaken to examine the impact of micronutrient treatment on rice. This research was conducted to examine the impact of micronutrients, specifically Zn, Cu, Mn, Fe, and B in conjunction with NPKS, on the growth and yield of boro rice.

## Materials and Methods

### Plant materials, experimental design, treatments, and growth conditions

The experiment was conducted in the net house of the School of Agriculture and Rural Development at Bangladesh Open University, Gazipur, Bangladesh. The rice variety BRRI dhan92 served as the planting material, using seeds procured from the Bangladesh Rice Research Institute (BRRI) in Gazipur, Bangladesh. The fundamental parameters of the soil were pH 6.5, organic carbon 1.68%, total nitrogen 0.17%, accessible P 12.9 ppm, total S 52 ppm, total Zn 9.07 ppm, and exchangeable K 0.17 meq per 100g of soil. Each container contained 12 kg of air-dried soil and was treated with the BRRI-recommended fertilizer dosage (BRRI, 2020) [6]. The experiment was conducted using a Completely Randomized Design (CRD) and replicated three times. Forty-day-old BRRI dhan92 seedlings were transplanted into pots, with three seedlings per hill. The following treatments were administered: T<sub>1</sub> = control (without fertilizer), T<sub>2</sub> = PKS (-N), T<sub>3</sub> = NPKS, T<sub>4</sub> = NPKS+Zn, T<sub>5</sub> = NPKS+Zn+Cu, T<sub>6</sub> = NPKS+Zn+Cu+Mn, T<sub>7</sub> = NPKS+Zn+Cu+Mn+F, and T<sub>8</sub> = NPKS+Zn+Cu+Mn+F+B. Zinc, copper, manganese, ferrous, and boron were applied according to experimental specifications using zinc sulphate (0.5%), copper sulphate (0.5%), manganese chloride (0.5%), ferrous sulphate (1%), and boric acid (0.2%) as foliar sprays during the tillering and reproductive stages.

### Measurement of growth parameter

The plant height was measured in centimeters (cm) from ground level to the tip of the leaf at 30 days after transplanting (DAT), 50 DAT, and at harvest. The number of tillers hill<sup>-1</sup> was recorded at 30 days after transplanting (DAT), 50 DAT, and at

harvest. Only tillers with three or more leaves were included in the count.

### Determination of SPAD Value

The leaf chlorophyll concentration was measured with a SPAD meter (Konica Minolta SPAD-502 Plus, Inc., Japan). Fully developed leaves were used to assess SPAD values. The average SPAD value was derived from three readings.

### Plant sampling and analysis

The total number of emerged panicles per hill was recorded at maturity. The overall grain count was determined by averaging the filled and unfilled grains from each pot, and the number of grains per panicle was recorded. One thousand grains were enumerated by the seed counting machine (Bioeurope ASC-TCP) from the total cleaned harvested grains and subsequently weighed using a digital electronic balance, with the weight recorded in grams. The grain sterility percentage was determined by dividing the number of unfilled grains by the total number of grains and then multiplying by 100. Grain sterility percentage = (Number of unfilled grains / Total number of grains) × 100. The weight of grains from each pot was measured and recorded in grams. The straw collected from each hill was oven-dried and subsequently weighed in grams hill<sup>-1</sup>.

### Determination of total N, available P, and K in grain and straw

Total nitrogen was quantified using the Kjeldahl method (Bremner & Mulvaney, 1982) [11], accessible phosphorus was assessed via the Bray 2 method (Bray & Kurtz, 1945) [10], and exchangeable potassium was extracted with 1 M NH<sub>4</sub>OAc at pH 7 (Benton, 2001) [8].

### Determination of Zn, Cu, Mn, Fe, and B in grain and straw

The AA-7000 atomic absorption spectrophotometer (Shimadzu) was employed to ascertain the concentrations of the micronutrients Zn, Cu, Mn, Fe, and B. The approach utilizes the atomic absorption spectrum of a sample to determine the concentrations of various analytes. It necessitates standards with defined analytical content to establish the correlation between observed absorbance and analytical concentration, hence relying on the Beer-Lambert law.

### Digestion of straw and grain samples

A 0.5 g sub-sample was placed into a dry, clean digestive conical flask. Subsequently, 5 mL of nitric acid was introduced to the sample and permitted to stand overnight in a fume hood. The following day, the conical flask was placed on a heating block and heated gradually to 120 °C over 2 hours, as outlined by Lindsay and Norvell (1978) [34]. After cooling, 2 mL of perchloric acid (HClO<sub>4</sub>) was added, and the mixture was allowed to stand for several minutes. The conical flask was heated to 120 °C once more. Heating was temporarily halted at the emergence of dense white vapors, after which the volume was decreased to 3-4 mL. The digest was cooled, diluted to 50 mL with deionized water, and filtered using Whatman No. 42 filter paper into a volumetric flask.

### Statistical analysis

Mean values were taken from measurements of three replicates, and the SD of the means was calculated. The collected data were analyzed statistically using one-way analysis of variance (ANOVA) with the CropstaT<sub>10</sub> software. Treatment means were compared by the least significant difference (LSD) test at a P ≤

0.05 level of significance.

## Results and Discussion

### Growth parameters

The application of micronutrients produced significant ( $P < 0.05$ ) effects on plant height at 30 days after transplanting (DAT) and 50 DAT. However, no significant differences in plant height were observed at harvest (Figure 1). At 30 DAT, the highest plant heights of 60.05 cm and 59.82 cm were recorded in treatments  $T_8$  and  $T_5$ , respectively, both of which were significantly greater ( $P < 0.05$ ) than  $T_3$ . At 50 DAT, the highest value of 85.5 cm was observed in  $T_4$ , which was significantly greater than  $T_3$  and statistically similar to the values of 84.22 cm and 82.83 cm in  $T_8$  and  $T_5$ , respectively. The shortest plants at all three stages (39.60, 51.73, and 59.93 cm) were consistently observed in  $T_1$  (control). Tahir and Yasin (2016) [47] reported that maximum plant height (195 cm) in maize was achieved when micronutrients (Zn 4.7%, B 1.0%, Fe 2%, Mn 2.0%, and Cu 0.3%) were applied at 1250 ml ha<sup>-1</sup> during the stem elongation stage. Similarly, Zayed *et al.* (2011) [56] found that combined applications of NPKS+Zn+Mn, NPKS+Fe+Mn and NPKS+Fe+Zn did not significantly affect rice growth. Lahijani *et al.* (2020) [33] also observed that micronutrient application had no significant effect on rice plant height. In contrast, other studies have reported significant effects of foliar nutrient application on rice plant height (Deswal & Pandurangam, 2018; Sultana *et al.*, 2018) [13, 46]. Khan *et al.* (2010) [31] demonstrated that foliar application of micronutrients (Fe 1%, Mn 2%, Zn 2%, Cu 1%, B 1%) at different wheat growth stages increased plant height.

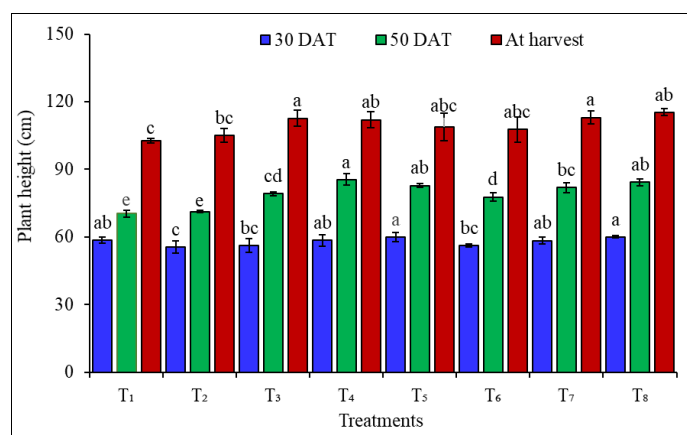


**Fig 1:** Effect of micronutrients on plant height at 30 DAT, 50 DAT, and at harvest of rice. Here,  $T_1$  = control (without fertilizer),  $T_2$  = PKS (–N),  $T_3$  = NPKS,  $T_4$  = NPKS+Zn,  $T_5$  = NPKS+Zn+Cu,  $T_6$  = NPKS+Zn+Cu+Mn,  $T_7$  = NPKS+Zn+Cu+Mn+F and  $T_8$  = NPKS+Zn+Cu+Mn+F+B. Data are mean  $\pm$  SD (standard deviation). Vertical bars represent LSD values at the 5% significance level. Different letters indicate significant differences between treatments at  $P < 0.05$ .

Tillering in rice represents a critical agronomic trait for grain production and serves as a model for studying branching in monocotyledonous plants. The influence of micronutrients on tiller production is illustrated in figure 2. The highest tiller counts 21.33 and 28.33 were recorded for treatment  $T_7$  at 30 days after transplanting (DAT) and 50 DAT, respectively, while the highest value at harvest was observed in  $T_8$ . Conversely, the lowest values of 18.66, 24.00, and 11.00 were recorded in  $T_1$  at

30 DAT, 50 DAT, and harvest, respectively. The number of tillers hill<sup>-1</sup> increased significantly over time, peaked at 50 DAT, and then declined slightly. These findings are consistent with previous reports by Radhika *et al.* (2013) [40], who indicated that various micronutrients (Fe-1.0%, Mn-0.5%, Zn-5.0%, Cu-0.35%, and B-0.05%) present in kicite may be effectively absorbed during growth stages, thereby enhancing enzyme and hormone activity and promoting the development of productive tillers. Additionally, Mahmoodi *et al.* (2020) [35] demonstrated that foliar nutrient applications at the transplanting, tillering, and panicle initiation stages influence the number of tillers per rice plant. Similar increases in tiller number following foliar nutrient application have been reported by other researchers (Farooq *et al.*, 2018; Khursheed *et al.*, 2018) [19, 32].

### SPAD value

Chlorophyll concentration in leaves is a critical indicator of plant yield because it plays a central role in photosynthesis. Data presented in figure 3 indicate that the application of Zn, Cu, Mn, Fe, and B, either individually or in combination, influenced SPAD values. At 30 days after transplanting (DAT), foliar application of treatment  $T_8$  significantly ( $P < 0.05$ ) increased the SPAD value to 43.36 compared to rice plants treated with  $T_3$  alone. At 50 DAT, a significant ( $P < 0.05$ ) increase in SPAD value was also observed for treatment  $T_8$ , reaching 48.56, compared to  $T_3$  alone. This value was statistically similar to those observed in treatments  $T_7$  (47.43) and  $T_4$  (47.26). The results suggest that SPAD values increased with plant age and with the application of boron (B) combinations. The lowest SPAD values, 36.83 and 35.17, were recorded in the control treatment ( $T_1$ ) at 30 DAT and 45 DAT, respectively. These findings are consistent with those of Wasaya *et al.* (2017) [50], who reported higher SPAD chlorophyll values in maize following the application of both Zn and B than in the control. This observation aligns with Berglund (2002) [9] and Huda *et al.* (2009) [28], who demonstrated that the addition of Zn and Fe increased both net photosynthetic rate and chlorophyll content in plants. Similarly, Deswal and Pandurangam (2018) [13] found that foliar nutrient application increased leaf chlorophyll concentration.

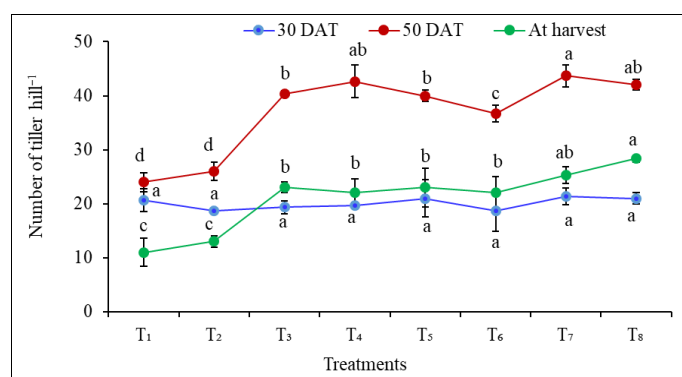


**Fig 2:** Effect of micronutrients on the number of tiller hill<sup>-1</sup> at 30 DAT, 50 DAT, and at harvest of rice. Here,  $T_1$  = control (without fertilizer),  $T_2$  = PKS (–N),  $T_3$  = NPKS,  $T_4$  = NPKS+Zn,  $T_5$  = NPKS+Zn+Cu,  $T_6$  = NPKS+Zn+Cu+Mn,  $T_7$  = NPKS+Zn+Cu+Mn+F and  $T_8$  = NPKS+Zn+Cu+Mn+F+B. Data are mean  $\pm$  SD (standard deviation). Vertical bars represent LSD values at the 5% significance level. Different letters indicate significant differences between treatments at  $P < 0.05$ .

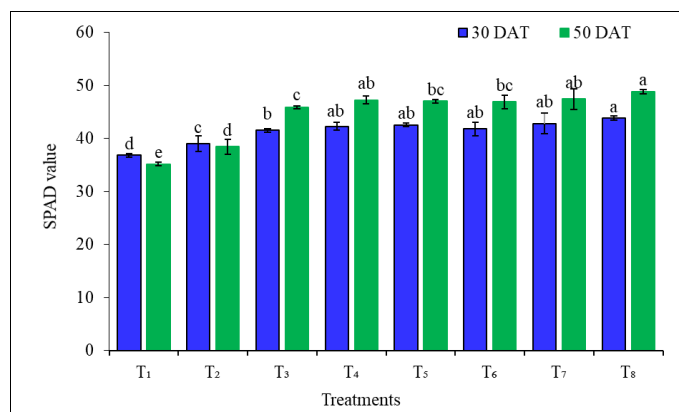


**Fig 3:** Effect of micronutrients on SPAD value at 30 DAT and 45 DAT of rice. Here, T<sub>1</sub> = control (without fertilizer), T<sub>2</sub> = PKS (–N), T<sub>3</sub> = NPKS, T<sub>4</sub> = NPKS+Zn, T<sub>5</sub> = NPKS+Zn+Cu, T<sub>6</sub> = NPKS+Zn+Cu+Mn, T<sub>7</sub> = NPKS+Zn+Cu+Mn+F and T<sub>8</sub> = NPKS+Zn+Cu+Mn+F+B. Data are mean ± SD (standard deviation). Vertical bars represent the LSD value at the 5% significance level. Different letters indicate significant differences between treatments at  $P < 0.05$ .

### Grain and straw weight

The data in table 1 indicate that the grain weight of rice (BRRI dhan92) was affected by several treatments. The grain weight of rice was similarly augmented by certain micronutrients (Table 1). The grain yield ranged from 20.92 g to 47.32 g ha<sup>-1</sup>. The treatment T<sub>8</sub> yielded a considerably higher grain weight (47.32 g hill<sup>-1</sup>) compared to the rice plants treated with T<sub>3</sub>, while the lowest grain weight was recorded in T<sub>1</sub> (Control) at 20.92 g. The grain weight resulting from various treatments can be ordered as follows: T<sub>8</sub> > T<sub>4</sub> > T<sub>6</sub> > T<sub>7</sub> > T<sub>5</sub> > T<sub>3</sub> > T<sub>2</sub> > T<sub>1</sub> (Table 1). The interventions in this investigation increased grain weight by 0.10% to 23.68% compared to T<sub>3</sub> (Table 1). The T<sub>8</sub> and T<sub>5</sub> yielded the biggest (23.68%) and lowest (0.10%) grain weight increases over T<sub>3</sub>, respectively. Malakouti (2000) [36] also reported that the use of individual micronutrients (Fe, Zn, Cu, and B) or a combination of Fe, Zn, Cu, and B with NPK fertilizer resulted in a 4 to 11% increase in wheat grain production. Ali *et al.* (2003) [2] demonstrated that the maximum significant paddy yield of 6087 kg ha<sup>-1</sup> was achieved with the application of NPK + Zn<sup>+2</sup> + Cu<sup>+2</sup> + Fe<sup>+2</sup> + Mn<sup>+2</sup>, compared to a yield of 4073 kg ha<sup>-1</sup> from the NPK treatment alone. Saikh *et al.* (2022) [42] noted that the foliar application of 0.5% ZnSO<sub>4</sub> at panicle initiation and one week post-flowering yielded the maximum grain output of 5.09 t ha<sup>-1</sup>, representing a 50.59% increase (3.38 t ha<sup>-1</sup>) compared to the control group. Tahir and Yasin (2016) [47] indicated that the foliar application of micronutrients (Zn 4.7%, B 1.0%, Fe 2%, Mn 2.0%, and Cu 0.3%) enhanced maize grain yield. Rao *et al.* (2013) found that 0.4 ppm boron significantly increased grain yield by 4–8%. Prior research has indicated substantial impacts of foliar nutrient spray on grain yields (Khursheed *et al.*, 2018; Sultana *et al.*, 2018) [32, 46].

On the other hand, the straw yield varied from 31.32 g to 93.26 g ha<sup>-1</sup>, with the minimum and maximum straw weights recorded in T<sub>1</sub> (Control) and T<sub>8</sub>, respectively. The treatment T<sub>8</sub> yielded the highest straw output (93.26 g), significantly ( $P < 0.05$ ) surpassing the straw of rice plants treated with T<sub>3</sub>, which was statistically comparable to T<sub>5</sub> and T<sub>6</sub>. The straw yield from various treatments can be ordered as follows: T<sub>8</sub> > T<sub>4</sub> > T<sub>7</sub> > T<sub>5</sub> > T<sub>3</sub> > T<sub>6</sub> > T<sub>2</sub> > T<sub>1</sub> (Table 1). The percentage increase in rice

(BRRI dhan92) straw yield resulting from various treatments ranged from 0.45 to 21.19 (Table 1) compared to T<sub>3</sub>. T<sub>8</sub> and T<sub>6</sub> produced the biggest (21.19%) and lowest (0.6%) straw yield increases over T<sub>3</sub>, respectively. The results concurred with the findings of Siddika *et al.* (2016) [44], who noted that the application of micronutrients such as Zn, Cu, Mn, and B had a significantly favorable impact on the grain and straw yields of rice (BRRI Dhan29) when combined with NPKS. Khan *et al.* (2010) [31] discovered that the foliar application of micronutrients (Fe= 1%, Mn= 2%, Zn= 2%, Cu= 1%, B= 1%) during various growth stages of wheat enhanced straw yield.

**Table 1:** Mean effect of micronutrients (Zn, Cu, Mn, Fe and B) on grain weight, straw weight of BRRI dhan92. Different letters indicate significant differences between treatments at  $P < 0.05$ .

| Treatment symbol | Grain weight (g hill <sup>-1</sup> ) | Straw weight (g hill <sup>-1</sup> ) | Increased grain weight (%) | Increased straw weight (%) |
|------------------|--------------------------------------|--------------------------------------|----------------------------|----------------------------|
| T <sub>1</sub>   | 20.92b                               | 31.32e                               | -                          | -                          |
| T <sub>2</sub>   | 24.46b                               | 41.67d                               | -                          | -                          |
| T <sub>3</sub>   | 38.26a                               | 76.95c                               | -                          | -                          |
| T <sub>4</sub>   | 45.47a                               | 86.86a                               | 18.84                      | 12.87                      |
| T <sub>5</sub>   | 38.3a                                | 77.42c                               | 0.10                       | 0.61                       |
| T <sub>6</sub>   | 41.29a                               | 76.60c                               | 7.91                       | 0.45                       |
| T <sub>7</sub>   | 40.16a                               | 82.12b                               | 4.96                       | 6.71                       |
| T <sub>8</sub>   | 47.32a                               | 93.26a                               | 23.68                      | 21.19                      |
| CV%              | 14.02                                | 7.23                                 | -                          | -                          |
| LSD (0.05)       | 9.0912                               | 8.9080                               | -                          | -                          |

**Note** - T<sub>1</sub> = control (without fertilizer), T<sub>2</sub> = PKS (–N), T<sub>3</sub> = NPKS, T<sub>4</sub> = NPKS+Zn, T<sub>5</sub> = NPKS+Zn+Cu, T<sub>6</sub> = NPKS+Zn+Cu+Mn, T<sub>7</sub> = NPKS+Zn+Cu+Mn+F and T<sub>8</sub> = NPKS+Zn+Cu+Mn+F+B.

### Yield contributing characters

At harvest, yield components, including the number of panicles hill<sup>-1</sup>, grains panicle<sup>-1</sup>, weight of 1000 grains, and sterility percentage were affected by the application of several micronutrients (Table 2). This study observed that the number of panicles hill<sup>-1</sup> ranged from 10.33 to 25.00 with the maximum recorded in T<sub>8</sub> being 25.00. No significant changes ( $P < 0.05$ ) were observed in the number of panicles hill<sup>-1</sup> among treatment means when compared to NPKS treatments alone. Conversely, the control treatment without micronutrient application yielded the lowest panicle count hill<sup>-1</sup> (10.33) as indicated in Table 2. The number of grains panicle<sup>-1</sup> ranged from 107.16 to 151.92, with the maximum value observed in T<sub>5</sub> (151.92), which was comparable to T<sub>8</sub> (142.99). The minimum quantity of grains panicle<sup>-1</sup> (107.16) was observed in T<sub>1</sub> (control) (Table 2). It was also noted that various micronutrients did not significantly affect the 1000–grain weight in BRRI dhan92 (Table 2). The sterility rate in the T<sub>8</sub> treatment was the lowest at 18.38%, compared to all other treatments. Rao *et al.* (2013) [41] noted that the application of boron led to an increase in grain number (25–45) and a decrease in the number of empty spikelet's. Furthermore, prior research has indicated substantial effects of foliar nutrition use on the quantity of filled grains panicle<sup>-1</sup> (Radhika *et al.*, 2013) [40]. Several prior studies indicated substantial impacts of foliar nutrient spray on 1000–grain weight (Khursheed *et al.*, 2018; Sultana *et al.*, 2018) [32, 46]. Nonetheless, several studies similarly reported no significant impacts of foliar nutrient spray on 1000–grain weight (Farooq *et al.*, 2018) [19]. Ambak and Tadano (1991) [3] reported that micronutrient treatment resulted in the lowest sterility rate in rice.

**Table 2:** Effect of micronutrients (Zn, Cu, Mn, Fe and B) on yield contributing characters of BRRI dhan92. Different letters indicate significant differences between treatments at  $P < 0.05$ .

| Treatment symbol | Panicles hill <sup>-1</sup> | Grains panicle <sup>-1</sup> | 1000-grain weight (g) | Sterility (%) |
|------------------|-----------------------------|------------------------------|-----------------------|---------------|
| T <sub>1</sub>   | 10.33c                      | 107.16b                      | 21.04a                | 26.29abc      |
| T <sub>2</sub>   | 12.66c                      | 111.16b                      | 21.49a                | 22.58bc       |
| T <sub>3</sub>   | 21.33ab                     | 115.74b                      | 20.28a                | 24.76abc      |
| T <sub>4</sub>   | 18.33b                      | 148.5a                       | 19.24a                | 32.57a        |
| T <sub>5</sub>   | 20.66ab                     | 151.92a                      | 21.32a                | 28.20ab       |
| T <sub>6</sub>   | 18.66b                      | 139.24a                      | 20.96a                | 23.74abc      |
| T <sub>7</sub>   | 21.00ab                     | 138.47a                      | 20.47a                | 27.07abc      |
| T <sub>8</sub>   | 25.00a                      | 142.99a                      | 21.10a                | 18.38c        |
| CV%              | 14.32                       | 6.59                         | 8.39                  | 19.92         |
| LSD (0.05)       | 4.63                        | 15.33                        | 3.04                  | 8.87          |

Note - T<sub>1</sub> = control (without fertilizer), T<sub>2</sub> = PKS (-N), T<sub>3</sub> = NPKS, T<sub>4</sub> = NPKS+Zn, T<sub>5</sub> = NPKS+Zn+Cu, T<sub>6</sub> = NPKS+Zn+Cu+Mn, T<sub>7</sub> = NPKS+Zn+Cu+Mn+F and T<sub>8</sub> = NPKS+Zn+Cu+Mn+F+B.

### Nutrient uptake

The macro- and micronutrient compositions in the grain and straw tissues were altered with the application of micronutrients. The average uptake of nutrients by rice grain ranged from 4.27 to 7.97 mg kg<sup>-1</sup> for N, 1.02 to 2.19 mg kg<sup>-1</sup> for P, 1.44 to 2.11 mg kg<sup>-1</sup> for K, 0.003 to 0.009 mg kg<sup>-1</sup> for Zn, 0.11 to 0.24 mg kg<sup>-1</sup> for Cu, 0.008 to 0.099 mg kg<sup>-1</sup> for Mn, 0.002 to 0.009 mg kg<sup>-1</sup> for Fe and 0.025 to 0.030 mg kg<sup>-1</sup> for B (Table 3). The

corresponding ranges of uptake of nutrients by straw were 6.27 to 10.96 mg kg<sup>-1</sup> for N, 10.12 to 16.99 mg kg<sup>-1</sup> for P, 12.84 to 23.89 mg kg<sup>-1</sup> for K, 0.004 to 0.076 mg kg<sup>-1</sup> for Zn, 0.18 to 0.27 mg kg<sup>-1</sup> for Cu, 0.0014 to 0.0199 mg kg<sup>-1</sup> for Mn, 0.920 to 1.94 mg kg<sup>-1</sup> for ferrous and 0.034 to 0.039 mg kg<sup>-1</sup> for B (Table 4). These results showed that the T<sub>8</sub> treatment maintained higher nutrient uptake across all nutrients, most likely owing to the higher yield recorded (Table 1). Under treatment T<sub>1</sub> (control), the lowest uptake values were recorded, reflecting the lowest yield. The use of micronutrients enhanced the absorption of both macronutrients and micronutrients. These results are consistent with those of Panhwar *et al.* (2015) [39], who reported that micronutrient application increased the uptake of both macronutrients and micronutrients. Furthermore, micronutrients, such as zinc and copper, can exhibit synergistic effects that enhance nutrient uptake in plants (Hewitt, 1983) [27]. This mutual effect of nutrients may cause micronutrient deficiency in the soil (Kausar *et al.*, 1976) [30]. Moreover, Yassen *et al.* (2010) [53] showed that spraying plants with Fe, Mn, and Zn increased grain concentrations of these elements compared with the control treatment. Furthermore, Gomaa *et al.* (2015) [23] indicated that the combined foliar application of micronutrients (Zn+Fe) markedly enhanced the concentrations of N, P, and K, as well as Zn and Fe, in wheat grain relative to the control group. In rice, foliar application of Zn markedly increased Zn accumulation in the grain (Yuan *et al.*, 2013) [55].

**Table 3:** Nutrient uptake (mg kg<sup>-1</sup>) of rice grain (BRRI dhan92) as influenced by different micronutrients. Different letters indicate significant differences between treatments at  $P < 0.05$ .

| Treatment symbol | N      | P      | K      | Zn      | Cu     | Mn      | Fe     | B        |
|------------------|--------|--------|--------|---------|--------|---------|--------|----------|
| T <sub>1</sub>   | 4.27f  | 1.00f  | 1.44c  | 0.003d  | 0.185f | 0.008b  | 0.920g | 0.028abc |
| T <sub>2</sub>   | 5.16e  | 1.34e  | 1.32c  | 0.006c  | 0.228g | 0.011b  | 1.48a  | 0.025c   |
| T <sub>3</sub>   | 6.1d   | 1.78c  | 1.67bc | 0.007bc | 0.219e | 0.019b  | 1.3b   | 0.028abc |
| T <sub>4</sub>   | 7.35b  | 1.7d   | 1.56c  | 0.046a  | 0.164f | 0.010bc | 0.95d  | 0.028abc |
| T <sub>5</sub>   | 7.18b  | 1.67d  | 1.49c  | 0.007bc | 0.219d | 0.012b  | 1.44e  | 0.029ab  |
| T <sub>6</sub>   | 6.97c  | 1.89b  | 1.98ab | 0.007bc | 0.202c | 0.011b  | 1.29c  | 0.029ab  |
| T <sub>7</sub>   | 7.23b  | 2.16a  | 2.01ab | 0.008bc | 0.250b | 0.099a  | 1.08f  | 0.025bc  |
| T <sub>8</sub>   | 7.97a  | 2.19a  | 2.11a  | 0.009b  | 0.270a | 0.099a  | 1.94f  | 0.030a   |
| CV%              | 2.79   | 3.40   | 2.40   | 15.21   | 0.38   | 11.72   | 3.75   | 2.14     |
| LSD (0.05)       | 0.4449 | 0.8580 | 0.8504 | 8.122   | 1.467  | 2.130   | 0.0854 | 1.381    |

Note - T<sub>1</sub> = control (without fertilizer), T<sub>2</sub> = PKS (-N), T<sub>3</sub> = NPKS, T<sub>4</sub> = NPKS+Zn, T<sub>5</sub> = NPKS+Zn+Cu, T<sub>6</sub> = NPKS+Zn+Cu+Mn, T<sub>7</sub> = NPKS+Zn+Cu+Mn+F and T<sub>8</sub> = NPKS+Zn+Cu+Mn+F+B.

**Table 4:** Nutrient uptake (mg kg<sup>-1</sup>) of rice straw (BRRI dhan92) as influenced by different micronutrients. Different letters indicate significant differences between treatments at  $P < 0.05$ .

| Treatment symbol | N       | P       | K       | Zn      | Cu      | Mn      | Fe      | B        |
|------------------|---------|---------|---------|---------|---------|---------|---------|----------|
| T <sub>1</sub>   | 6.27f   | 10.12d  | 12.84f  | 0.0049b | 0.1857f | 0.0014e | 0.9201e | 0.0377b  |
| T <sub>2</sub>   | 7.69e   | 11.84c  | 14.52e  | 0.0041b | 0.2285c | 0.0086b | 1.482b  | 0.0347c  |
| T <sub>3</sub>   | 8.8d    | 15.58ab | 20.87d  | 0.0062b | 0.2198d | 0.0081d | 1.3c    | 0.0387ab |
| T <sub>4</sub>   | 10.05bc | 14.9b   | 21.9c   | 0.0065b | 0.1646g | 0.0144b | 0.9516e | 0.0355c  |
| T <sub>5</sub>   | 9.67c   | 15.36b  | 22.29bc | 0.0062b | 0.2192d | 0.0115c | 1.44b   | 0.0392a  |
| T <sub>6</sub>   | 9.16d   | 14.85b  | 22.43bc | 0.069a  | 0.2024e | 0.0092d | 1.29c   | 0.0351c  |
| T <sub>7</sub>   | 10.12b  | 16.36a  | 23.02ab | 0.071a  | 0.2509b | 0.0099d | 1.08d   | 0.0359c  |
| T <sub>8</sub>   | 10.96a  | 16.33a  | 23.89a  | 0.076a  | 0.2701a | 0.0199a | 1.949a  | 0.0375b  |
| CV%              | 1.69    | 2.50    | 13.85   | 13.75   | 1.31    | 25.43   | 2.55    | 8.00     |
| LSD (0.05)       | 0.1937  | 0.0753  | 0.4118  | 2.945   | 3.802   | 0.0152  | 1.585   | 3.954    |

Note - T<sub>1</sub> = control (without fertilizer), T<sub>2</sub> = PKS (-N), T<sub>3</sub> = NPKS, T<sub>4</sub> = NPKS+Zn, T<sub>5</sub> = NPKS+Zn+Cu, T<sub>6</sub> = NPKS+Zn+Cu+Mn, T<sub>7</sub> = NPKS+Zn+Cu+Mn+F and T<sub>8</sub> = NPKS+Zn+Cu+Mn+F+B.

### Conclusion

The use of micronutrients in addition to NPKS resulted in superior performance in plant height, tiller number hill<sup>-1</sup>, number of grains panicle<sup>-1</sup>, SPAD value, grain yield, straw yield, and nutrient uptake in rice compared with NPKS alone. The combined use of NPKS+Zn+Cu+Mn+Fe+B with NPKS was

most effective in improving rice growth, yield, and nutrient absorption. According to these data, the treatments Zn and Zn+Cu+Mn+F+B, together with NPKS fertilizers, might represent a potential combination for optimizing rice output and enhancing its nutritional content to address human nutrient deficiencies.

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