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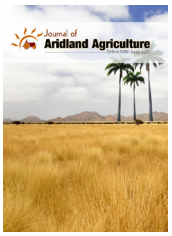

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Foliar supplementation of phosphorus and zinc enhanced the yield of *Boro* rice

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ABSTRACT

Supplying phosphorus and zinc through foliar supplementation can be beneficial for crops experiencing higher demand compared to supply from soil. Phosphorus and zinc, an important micronutrient significantly influence various yield components of *Boro* rice production. A research investigation was conducted to evaluate the impact of foliar application of phosphorus and zinc on the *Boro* rice yield. The research included two varieties *cv.* BRRI dhan28 and BRRI dhan89 and five treatments of phosphorus and zinc fertilizer management *viz.* F_1 (Recommended dose of fertilizers, RDF), F_2 (RDF + foliar supplementation of 1% P at panicle initiation stage), F_3 (RDF + foliar supplementation of 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage), F_4 (RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) and F_5 (75% RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage). The study was conducted employing a randomized complete block design and it was replicated thrice. The application of phosphorus and zinc fertilizer through foliar supplementation significantly impacted the yield components of *Boro* rice. The highest plant height (96.60 cm), total tillers hill^{-1} (11.80), effective tillers hill^{-1} (11.50), panicle length (24.10 cm), grains panicle^{-1} (129.43), 1000-grain weight (25.12 g), grain yields (8.01 t ha^{-1}), straw yields (8.04 t ha^{-1}), biological yield (16.05) and harvest index (49.90 %) were resulted with BRRI dhan89 when applied with RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage. Based on the findings, it can be inferred that BRRI dhan89 resulted in superior performance compared to BRRI dhan28 and RDF with a foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at the panicle initiation stage performed best for BRRI dhan89.

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INTRODUCTION

Rice (*Oryza sativa* L) holds a prominent position among cereal crops globally functioning as a primary food source for a substantial portion of the Earth's inhabitants. It holds a significant position in the economies of rural areas in Asia, Africa and Latin America serving as a staple in the diet of many individuals (Maqsood *et al.*, 2013). More than 170 million hectares of cultivated land are utilized to cultivate rice worldwide that was produced in more than a hundred countries and resulting in an annual production of over 800 million tons (FAO, 2020). Rice contributes 15% of the protein and 21% of the energy consumed globally by humans per person (IRRI, 2010). Bangladesh holds a prominent position among the world's leading rice producing nations securing the third spot in global grain production (FAO, 2022). In Bangladesh, where agriculture boasts a substantial 40.6% employment rate and contributes 11.61% to the GDP, it stands as the dominant sector in the country's economy (BBS, 2022). It holds a crucial position in the economic landscape of Bangladesh making a substantial impact on the GDP, creating employment opportunities and ensuring food availability.

Phosphorus plays a crucial role as a fundamental element in influencing the growth and productivity of plants. The quantity of soil available phosphorus is often inadequate for plants to reach their maximum growth and development due to the fixation of phosphorus in the soil. Phosphorus plays an important role in various cellular and systemic processes of plant growth such as photosynthesis, respiration and nitrogen fixation (Malhotra, 2018). Zinc is a vital element that plants absorb as a divalent cation. In plants, zinc plays a crucial metabolic role. Additionally, zinc has a role in the Krebs cycle and energy production (Mousavi, 2011).

Conventional agricultural practices often involve soil applied fertilizers to address nutrient deficiencies. However, this approach has limitations including nutrient fixation, leaching and the time lag between application and nutrient availability. Soil fertilization is mostly done based on soil analysis while foliar application is mainly done based on leaf visual cues or plant tissue analysis. Foliar fertilization of plants can supplement soil fertilization (Fageria *et al.*, 2009) and it can be beneficial for a crop when its requirements exceed the amount available in the soil (Dey *et al.*, 2023). As an alternative or supplementary strategy, foliar nutrient supplementation has gained prominence. This method involves the direct application of nutrient solutions to a plant's foliage, facilitating rapid absorption and utilization. According to Ling and Silberbush (2002), supplying nutrients via foliage is a commonly employed technique to rectify plant nutritional deficiencies arising from inadequate nutrient distribution to the root system. In *Boro* rice cultivation which occurs during the dry season when water is relatively abundant, the efficient management of nutrients gains paramount importance. Phosphorus and zinc deficiencies during this critical period can lead to significant yield losses and diminished grain quality. Therefore, the present study was undertaken to assess the yield performance *Boro* rice under foliar supplementation of phosphorus and zinc fertilizers.

MATERIALS AND METHODS

Experimental Location and Experimentation

The study was conducted at the Agronomy Field Laboratory (latitude of 24° 75' North and longitude of 90° 50' East), Bangladesh Agricultural University, Mymensingh, Bangladesh. The ground of the research plot belongs to the Old Brahmaputra alluvial zone (AEZ 9) having of pH 6.8. The study comprised two cultivars *cv.* BRRI dhan28 and BRRI dhan89 and five treatments of phosphorus and zinc supplementation *viz*. F_1 (RDF), F_2 (RDF + foliar supplementation of 1% P at panicle initiation stage), F_3 (RDF + foliar supplementation of 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage), F_4 (RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) and F_5 (75% RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage). The study was structured using a randomized complete block design and replicated thrice. The research was conducted with 30 plots and all plots measured 4.0 m × 2.5 m. The spacing among two unit cells was 0.5 m while the distance between blocks was 1.0 m. The treatments were randomly distributed across the plots.

Crop Husbandry

BRRI dhan28 and BRRI dhan89 were selected as test crops of the research. The rice variety seeds were obtained from the Agronomy Field Laboratory at Bangladesh Agricultural University, Mymensingh, Bangladesh. The gravity method is employed to choose robust and weighty seeds. Subsequently, the selected seeds were undergone a 24 hour soaking period in a water filled bucket. Afterward, they were taken out of the water and placed inside a jute bag. Seeds were begun to germinate after 48 hours and sown after 72 hours in the nursery. The study area was fertilized using Urea, TSP, MoP, Gypsum and Zinc Sulphate @ 160, 60, 80, 60 and 6 kg ha^{-1}. All fertilizers, except for urea were administered prior to the completion of the last soil preparation. Conversely, urea was employed at three distinct time schedules: 15, 30 and 45 days following the transplanting process. Phosphorus and zinc fertilizers were applied according to the technical requirements for treatment. 1% P and 0.5% Zn was prepared by adding 12.25 g KH_2PO_4 to 18 L of water and 90 g of $ZnSO_4.7H_2O$ in 18 L of water sprayed in a specific plot by manual sprayer. Seedlings of 40 days old were pulled out of the nursery in the early morning of transplanting day. Seedlings were pulled out of the bed and transplanted. The seedlings were arranged at intervals of 25 cm by 15 cm within each cluster with two seedlings per cluster. Irrigation was carried out as necessary to ensure that the field retains adequate moisture. Excess water was removed from the field 15 days before harvest.

Data Collection

The harvest was conducted at the point of full maturity marked by 90% of the seeds displaying a golden yellow hue. Excluding border hills the data on various vegetation characteristics was documented through the random selection of five hills as of every plot. BRRI dhan28 was harvested earlier compared to BRRI dhan89. The produce harvested from each plot was individually grouped, appropriately tagged and dispatched to the place where it was threshed. The grains were then pounded with a pedal thresher. The seeds in $plot^{-1}$ were cleaned, weighed and their grain yield was documented. The straws were cleaned, dried and weighed to determine the yield. Subsequently, the paddy and straw production in $plot^{-1}$ were transformed into t ha^{-1}. Information regarding yield components and yields were collected on various sampling days and during harvest, involving the random selection of five plant samples from each plot.

Statistical Analysis

The average of all treatments was computed and an analysis of variance was performed for each studied trait with the MSTAT package. The dissimilarities along with treatment were assessed through Duncan's Multiple Range Test (Gomez & Gomez, 1984).

RESULTS

Plant Height

The variation of plant height was remarkably subjective with the different rice varieties, levels of phosphorus and zinc fertilizers as well as their combined effects. The experimental findings recorded where the peak plant height (95.43 cm) was obtained in BRRI dhan89 comparison to BRRI dhan28 (94.19 cm) (Table 1). With P and Zn fertilizer, research results showed that the highest plant (95.77 cm) was recorded in F_4 (RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) was identical to F_3 (95.44 cm), F_5

(94.85 cm) and F_2 (94.93 cm). In compare, the shortest height of plant (93.07 cm) resulted in F_1 (RDF) and it was identical to F_2 (94.93 cm) and F_5 (94.85 cm) (Table 1). When interacts, the results showed that the maximum height of the plant (96.60 cm) was calculated from BRRI dhan89 with F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) which was identical to V_2F_3 (96.51 cm), V_2F_2 (95.55 cm), V_2F_5 (95.50 cm), V_1F_4 (94.93 cm), V_1F_3 (94.38 cm), V_1F_2 (94.30 cm) and V_1F_5 (94.20 cm). The minimum height of the plant (93.00 cm) resulted from BRRI dhan89 with F_1 (RDF) and it was identical to V_1F_1 (93.13 cm) (Table 2).

Number of Total Tillers Hill^{-1}

There was a remarkable dissimilarity in the total tillers hill^{-1} when considering the combination of variety, phosphorus levels and zinc fertilizer levels. The uppermost quantity of total tillers hill^{-1} (11.28) was established in BRRI dhan89 compared to BRRI dhan28 (9.41) (Table 1). The maximum tillers hill^{-1} (11.10) resulted in F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) was statistically similar to F_3 (10.70), F_5 (10.23) and F_2 (10.39). Conversely, the least tillers hill^{-1} (9.32) was calculated in F_1 (RDF) that was identical to F_2 (10.39), F_3 (10.70) and F_5 (10.23) (Table 1). The highest total tillers hill^{-1}(11.80) resulted from BRRI dhan89 with F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) that was identical to V_2F_3 (11.67), V_2F_5 (11.33), V_2F_2 (11.32), V_2F_1 (10.30) and V_1F_4 (10.40). The minimum total tillers hill^{-1} (8.33) was calculated from BRRI dhan28 with F_1 (RDF), that was identical to V_1F_5 (9.13), V_1F_2 (9.47), V_1F_3 (9.73), V_1F_4 (10.40) and V_2F_1 (10.30) (Table 2).

Number of Effective Tillers Hill^{-1}

Variety and fertilizers management demonstrated variability in the number of effective tillers hill^{-1} (Table 1). The highest result (10.81) was calculated in BRRI dhan89 compared to BRRI dhan28 (8.88). The uppermost findings (10.72) was calculated in F_4 (RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) and is

Table 1: Effect of variety and P and Zn fertilizer management on yield attributes of *Boro* rice

Treatment	Plant height (cm)	Total tillers hill^{-1} (no.)	Effective tillers hill^{-1} (no.)	Non-effective tillers hill^{-1} (no.)	Panicle length (cm)	Grains panicle^{-1} (no.)
Variety						
V_1	94.19^{b}	9.41^{b}	8.88^{b}	0.53	23.32^{b}	121.32^{b}
V_2	95.43^{a}	11.28^{a}	10.81^{a}	0.48	23.85^{a}	123.57^{a}
Sig. level	*	**	**	NS	*	*
CV (%)	6.45	11.60	8.99	9.29	5.40	6.32
Fertilizer						
F_1	93.07^{b}	9.32^{b}	8.85^{c}	0.47	23.00^{b}	117.73^{b}
F_2	94.93^{ab}	10.39^{ab}	9.93^{ab}	0.46	23.71^{ab}	123.79^{ab}
F_3	95.44^{a}	10.70^{ab}	10.28^{ab}	0.42	23.74^{a}	124.36^{ab}
F_4	95.77^{a}	11.10^{a}	10.72^{a}	0.38	23.91^{a}	126.09^{a}
F_5	94.85^{ab}	10.23^{ab}	9.43^{bc}	0.80	23.56^{ab}	120.24^{ab}
Sig. level	*	*	*	NS	*	*
CV (%)	6.45	11.60	8.99	9.29	5.40	6.32

Means with the same letters or without letters within the same column do not differ significantly. **=Significant at 1% level of probability, *=Significant at 5% level of probability, NS=Not significant.V_1-BRRI dhan28, V_2-BRRI dhan89, F_1-Recommended dose of fertilizers (RDF), F_2-RDF+foliar application of 1% P at panicle initiation stage, F_3-RDF+foliar application of 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_4-RDF+foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_5-75% RDF+foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage.

Table 2: Interaction effect of variety and P and Zn fertilizer management on yield attributes of *Boro* rice

Variety × Fertilizer	Plant height (cm)	Total tillers hill^{-1} (no.)	Effective tillers hill^{-1} (no.)	Non-effective tillers hill^{-1} (no.)	Panicle length (cm)	Grains panicle^{-1} (no.)
$V_1 \times F_1$	93.13^{bc}	8.33e	7.67^{d}	0.67^{ab}	22.54^{b}	118.48^{b}
$V_1 \times F_2$	94.30^{ab}	9.47^{c-e}	8.80^{cd}	0.67^{ab}	23.45^{ab}	122.20^{ab}
$V_1 \times F_3$	94.38^{ab}	9.73^{b-e}	9.27^{c}	0.47^{ab}	23.5^{ab}	122.60^{ab}
$V_1 \times F_4$	94.93^{ab}	10.40^{a-d}	9.93^{bc}	0.47^{ab}	23.72^{ab}	122.76^{ab}
$V_1 \times F_5$	94.20^{ab}	9.13^{de}	8.73^{cd}	0.40^{ab}	23.38^{ab}	120.55^{ab}
$V_2 \times F_1$	93.00^{bc}	10.30^{a-e}	10.03^{a-c}	0.27^{ab}	23.46^{ab}	116.97^{b}
$V_2 \times F_2$	95.55^{ab}	11.32^{a}-^{c}	11.07^{ab}	0.25^{b}	23.96^{a}	125.37^{ab}
$V_2 \times F_3$	96.51^{a}	11.67^{ab}	11.30^{ab}	0.37^{ab}	23.99^{a}	126.12^{ab}
$V_2 \times F_4$	96.60^{a}	11.80^{a}	11.50^{a}	0.30^{ab}	24.10^{a}	129.43^{a}
$V_2 \times F_5$	95.50^{ab}	11.33^{a-c}	10.13^{a-c}	1.21^{a}	23.74^{ab}	119.93^{ab}
Sig. level	*	*	*	*	*	*
CV (%)	6.45	11.60	8.99	9.29	5.40	6.32

Means with the same letters or without letters within the same column do not differ significantly. *=Significant at 5% level of probability, NS=Not significant. V_1-BRRI dhan28, V_2-BRRI dhan89, F_1-Recommended dose of fertilizers (RDF), F_2-RDF+foliar application of 1% P at panicle initiation stage, F_3-RDF+foliar application of 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_4-RDF+foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_5-75% RDF+foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage

statistically similar to F_3 (10.28) and F_2 (9.93). Conversely, the minimum effective tillers hill^{-1} (8.85) was calculated in F_1 (RDF) that was identical to F_5 (9.43) (Table 1). The significant interaction observed was between the levels of phosphorus and zinc fertilizers and different varieties impacting the quantity of effective tillers hill^{-1} (Table 2). The maximum amount of effective tillers hill^{-1}(11.50) was calculated from BRRI dhan89 with F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) which was identical to V_2F_3 (11.30), V_2F_2 (11.07), V_2F_5 (10.13) and V_2F_1 (10.03). The minimum quantity of effective tillers hill^{-1} (7.67) was calculated from BRRI dhan28 with F_1 (RDF) and it was identical to V_1F_2 (8.80) and V_1F_5 (8.73).

Number of Non-effective Tillers Hill^{-1}

Variety, fertilizer levels and interactions did not exhibit a statistically significant distinction in the number of non-effective tillers hill^{-1}. The maximum non-effective tillers hill^{-1} (0.53) was found in BRRI dhan28 compared to BRRI dhan89 (0.48) (Table 1). The highest non-effective tillers hill^{-1} (0.80) was found in F_5 (75% RDF+ foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage). Conversely, the least one (0.38) resulted in F_4 (RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at the panicle initiation stage) (Table 1). The highest non-effective tillers hill^{-1}(1.21) was obtained from BRRI dhan89 with F_5 (75% RDF+ foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at the panicle initiation stage) and it was identical to V_2F_3 (0.37), V_2F_4 (0.30), V_2F_1 (0.27), V_1F_1 (0.67), V_1F_2 (0.67), V_1F_3 (0.47), V_1F_4 (0.47) and V_1F_5 (0.40). The minimum one (0.25) was calculated from BRRI dhan89 with F_2 (RDF + foliar supplementation of 1% P at panicle initiation stage) and it was identical to V_2F_3 (0.37), V_2F_4 (0.30), V_2F_1 (0.27), V_1F_1 (0.67), V_1F_2 (0.67), V_1F_3 (0.47), V_1F_4 (0.47) and V_1F_5 (0.40) (Table 2).

Panicle Length

The significant impact on panicle length resulted from the variety, fertilizer levels and combined interactions. The uppermost panicle length (23.85 cm) resulted in BRRI dhan89 compared to BRRI dhan28 (23.32 cm) (Table 1). The longest panicle length (23.91 cm) is recorded from F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) was statistically similar to F_3 (23.74 cm), F_5 (23.56 cm) and F_2 (23.71 cm). In contrast, the shortest panicle (23.00 cm) was calculated in F_1 (RDF) that was at par with F_5 (23.56 cm) and F_2 (23.71 cm) (Table 1). The results show that the highest panicle (24.10 cm) was calculated from BRRI dhan89 with F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) and it was identical to V_2F_3 (23.99 cm), V_2F_2 (23.96 cm), V_2F_5 (23.74 cm), V_2F_1 (23.46 cm), V_1F_4 (23.72 cm), V_1F_3 (23.50 cm), V_1F_2 (23.45 cm) and V_1F_5 (23.38 cm). The lowest one (22.54 cm) was resulted in BRRI dhan28 with F_1 (RDF), which was statistically similar to V_1F_4 (27.72 cm), V_1F_3 (23.50 cm), V_1F_2 (23.45 cm), V_1F_5 (23.38 cm) and V_2F_5 (23.74 cm) (Table 2).

Number of Grains Panicle^{-1}

Grains panicle^{-1} was significantly affected by variety, fertilizer levels and their interactions. The maximum number of grains panicle^{-1} (123.57) was found in BRRI dhan89 compared to BRRI dhan28 (121.32) (Table 1). The highest grains panicle^{-1} (126.09) was counted in F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) was identical to F_3 (124.36), F_2 (123.79) and F_5 (120.24). Conversely, the minimum grains panicle^{-1} (117.73) was calculated in F_1 (RDF) which was identical to F_3 (124.36), F_2 (123.79) and F_5 (120.24) (Table 1). The utmost grains panicle^{-1} (129.43) was counted from BRRI dhan89 with F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) which was identical to V_2F_3 (126.12), V_2F_2 (125.37), V_2F_5 (119.93), V_1F_2 (122.20), V_1F_3 (122.60), V_1F_4 (122.76) and V_1F_5 (120.55). The least grains panicle^{-1} (116.97) was calculated from BRRI dhan89 with F_1 (RDF) which was identical to V_2F_3 (126.12), V_2F_2 (125.37), V_2F_5 (119.93), V_1F_1 (118.48), V_1F_2 (122.20), V_1F_3 (122.60), V_1F_4 (122.76) and V_1F_5 (120.55) (Table 2).

Number of Sterile Spikelets Panicle^{-1}

The variety, fertilizer levels and their interactions collectively led to a notable influence on the number of sterile spikelets panicle^{-1}. The higher number of sterile spikelets panicle^{-1} (13.65) was calculated in BRRI dhan28 compared to BRRI dhan89 (13.33) (Table 2). The uppermost result (14.25) was counted in F_1 (RDF) which was identical to F_2 (13.64) and F_5 (13.53). In contrast, the minimum sterile spikelets panicle^{-1} (12.80) was resulted in F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) was identical to F_3 (13.24) and F_5 (13.53) (Table 3). The uppermost finding (14.64) resulted from BRRI dhan28 with F_1 (RDF) which was

Table 3: Effect of variety and P and Zn fertilizer management on yield attributes, biological yield and harvest index of *Boro* rice

Treatment	Sterile spikelets panicle^{-1} (no.)	1000-grain weight (g)	Biological yield (t ha^{-1})	Harvest index (%)
Variety				
V_1	13.65	24.32^{b}	10.47^{b}	48.39^{b}
V_2	13.33	24.91^{a}	14.97^{a}	49.67^{a}
Sig. level	NS	**	**	**
CV (%)	5.76	11.26	7.09	6.93
Fertilizers				
F_1	14.25^{a}	24.41^{b}	12.42^{b}	49.03^{a}
F_2	13.64^{ab}	24.62^{ab}	12.53^{b}	49.05^{a}
F_3	13.24^{bc}	24.66^{ab}	12.62^{b}	48.72^{ab}
F_4	12.80^{c}	24.83^{a}	13.46^{a}	48.88^{ab}
F_5	13.53^{a-c}	24.56^{ab}	12.58^{b}	49.46^{a}
Sig. level	*	*	**	*
CV (%)	5.76	11.26	7.09	6.93

Means with the same letters or without letters within the same column do not differ significantly. **=Significant at 1% level of probability, *=Significant at 5% level of probability, NS=Not significant.V_1-BRRI dhan28, V_2-BRRI dhan89, F_1-Recommended dose of fertilizers (RDF), F_2-RDF+foliar application of 1% P at panicle initiation stage, F_3-RDF+foliar application of 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_4-RDF+foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_5-75% RDF+foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage

identical to V_1F_2 (13.59), V_1F_5 (13.93), V_2F_1 (13.85) and V_2F_2 (13.69). The minimum one (12.61) which was resulted from BRRI dhan89 with F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) which was identical to V_1F_2 (13.59), V_1F_3 (13.10), V_1F_4 (12.99), V_2F_2 (13.69), V_2F_3 (13.37) and V_2F_5 (13.12) (Table 4).

1000-Grain Weight

The variety, fertilizer levels and their interactions collectively led to a notable influence on the weight of 1000 grains. The higher 1000-grain weight (24.91 g) resulted in BRRI dhan89 compared to BRRI dhan28 (24.32 g) (Table 2). The maximum one (24.83 g) resulted in F_4 (RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) was identical to F_3 (24.66 g), F_2 (24.62 g) and F_5 (24.56 g). Conversely, the lowest maximum 1000-grain weight (24.41 g) was resulted in F_1 (RDF) which was identical to F_3 (24.66 g), F_2 (24.62 g) and F_5 (24.56 g) (Table 2). The uppermost finding (25.12 g) counted from BRRI dhan89 with F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) which was identical to V_2F_1 (24.62), V_2F_2 (24.97), V_2F_3 (25.00) and V_2F_5 (24.87). The minimum 1000-grain weight (24.20) resulted from BRRI dhan28 with F_1 (RDF) which was identical to V_1F_2 (24.27), V_1F_3 (24.32), V_1F_4 (24.55), V_1F_5 (24.25) and V_2F_1 (24.62) (Table 4).

Grain Yield

The variety, fertilizer levels and their interactions collectively led to a notable influence on the grain yield. The highest result (7.44 t ha^{-1}) was found in BRRI dhan89 compared to BRRI dhan28 (5.06 t ha^{-1}) (Figure 1). Figure 1 indicated that the F_4 (RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at the panicle initiation stage) produced the highest grain yield (6.60 t ha^{-1}). Conversely, the lowest one (6.10 t ha^{-1}) resulted in F_1 (RDF) followed by F_2 (6.16 t ha^{-1}), F_3 (6.17 t ha^{-1}) and F_5 (6.23 t ha^{-1}) (Figure 1). The maximum grain yield (8.01 t ha^{-1}) was counted from BRRI dhan89 with F_4 (RDF + foliar application of both 1% P and 0.5% Zn). The minimum grain yield (4.98 t ha^{-1}) resulted from BRRI dhan28 with F_1 (RDF) which was identical to V_1F_2 (5.01 t ha^{-1}), V_1F_3 (5.03 t ha^{-1}), V_1F_4 (5.20 t ha^{-1}) and V_1F_5 (5.09 t ha^{-1}) (Figure 1).

Table 4: Interaction effect of variety and P and Zn fertilizer management on yield attributes, biological yield and harvest index of *Boro* rice

Variety × Fertilizer	Sterile spikelets panicle^{-1} (no.)	1000-grain weight (g)	Biological yield (t ha^{-1})	Harvest index (%)
$V_1 \times F_1$	14.64^{a}	24.20^{c}	10.25^{c}	48.66^{a-c}
$V_1 \times F_2$	13.59^{a-c}	24.27^{c}	10.34^{c}	48.50^{a-c}
$V_1 \times F_3$	13.10^{bc}	24.32^{c}	10.53^{c}	47.77^{c}
$V_1 \times F_4$	12.99^{bc}	24.55^{bc}	10.87^{c}	47.86^{bc}
$V_1 \times F_5$	13.93^{ab}	24.25^{c}	10.36^{c}	49.17^{a-c}
$V_2 \times F_1$	13.85^{ab}	24.62^{a-c}	14.59^{b}	49.41^{ab}
$V_2 \times F_2$	13.69^{a-c}	24.97^{ab}	14.72^{b}	49.61^{a}
$V_2 \times F_3$	13.37^{bc}	25.00^{ab}	14.71^{b}	49.67^{a}
$V_2 \times F_4$	12.61^{c}	25.12^{a}	16.05^{a}	49.90^{a}
$V_2 \times F_5$	13.12^{bc}	24.87^{ab}	14.80^{b}	49.74^{a}
Sig. level	*	*	*	*
CV (%)	5.76	11.26	7.09	6.93

Means with the same letters or without letters within the same column do not differ significantly. *=Significant at 5% level of probability, NS=Not significant. V_1-BRRI dhan28, V_2-BRRI dhan89, F_1-Recommended dose of fertilizers (RDF), F_2-RDF+foliar application of 1% P at panicle initiation stage, F_3-RDF + foliar application of 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_4-RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_5-75% RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage

Straw Yield

The variety, fertilizer levels and their interactions collectively led to a notable influence on the straw yield. The higher straw yield (7.54 t ha^{-1}) was calculated in BRRI dhan89 compared to BRRI dhan28 (5.40 t ha^{-1}) (Figure 2). The uppermost grain yield (6.86 t ha^{-1}) was found in F_4 (RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at the panicle initiation stage). Conversely, the minimum result (6.42 t ha^{-1}) was calculated in F_1 (RDF) followed by F_2 (6.37 t ha^{-1}), F_3 (6.45 t ha^{-1}) and F_5 (6.35 t ha^{-1}) (Figure 2). The highest straw yield (8.04 t ha^{-1}) was counted from BRRI dhan89 with F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at the panicle initiation stage). The smallest straw yield (5.26 t ha^{-1}) was calculated from BRRI dhan28 with F_1 (RDF) which was identical to V_1F_2 (5.32 t ha^{-1}), V_1F_3 (5.50 t ha^{-1}), V_1F_4 (5.67 t ha^{-1}) and V_1F_5 (5.27 t ha^{-1}) (Figure 2).

Biological Yield

The variety, fertilizer levels and their interactions collectively led to a notable influence on the biological yield. The higher biological yield (14.97 t ha^{-1}) resulted in BRRI dhan89 compared to BRRI dhan28 (10.47 t ha^{-1}) (Table 2). The maximum result (13.46 t ha^{-1}) was found in F_4 (RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at the panicle initiation stage). Conversely, the minimum one (12.42 t ha^{-1}) was counted in F_1 (RDF) followed by F_2 (12.53 t ha^{-1}), F_3 (12.62 t ha^{-1}) and F_5 (12.58 t ha^{-1}) (Table 2). The utmost finding (16.05 t ha^{-1}) was found from BRRI dhan89 with F_4 (RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at the panicle initiation stage). The lowest one (10.25 t ha^{-1}) was calculated from BRRI dhan28 with F_1 (RDF) which was identical to V_1F_2 (10.34 t ha^{-1}), V_1F_3 (10.53 t ha^{-1}), V_1F_4 (10.87 t ha^{-1})and V_1F_5 (10.36 t ha^{-1}) (Table 4).

Harvest Index

The variety, fertilizer levels and their interactions collectively led to a notable influence on the harvest index. The maximum harvest index (49.67%) was calculated in BRRI dhan89 and the minimum one (48.39%) resulted in BRRI dhan28 (Table 2). The maximum harvest index (49.46%) was calculated in F_5 (75% RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at the panicle initiation stage) which was identical to F_3 (48.72%) and F_4 (48.88%), F_2 (49.05%) and F_1 (49.03%). Conversely, the minimum harvest index (48.72%) was calculated in F_3 (RDF + foliar supplementation of 0.5% $ZnSO_4.7H_2O$ at

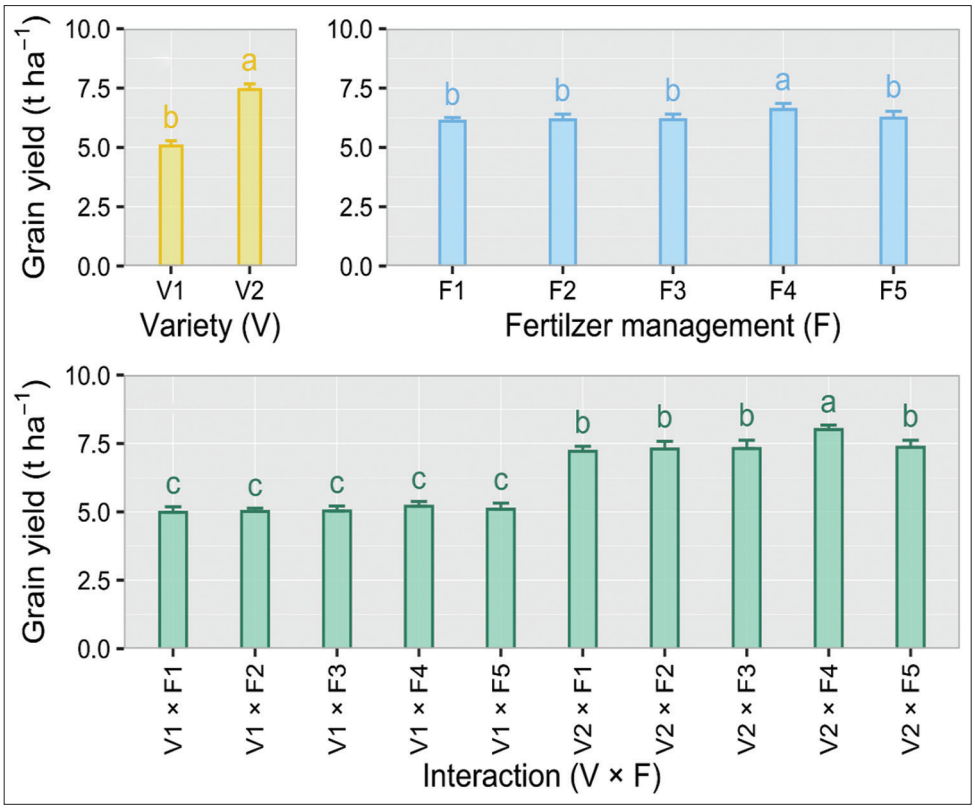

Figure 1: Effect of variety, fertilizer management and their interaction on the grain yield of *Boro* rice. V_1 - BRRI dhan28, V_2 - BRRI dhan89, F_1 - Recommended dose of fertilizers (RDF), F_2 - RDF + foliar application of 1% P at panicle initiation stage, F_3 - RDF + foliar application of 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_4 - RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_5 - 75% RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage

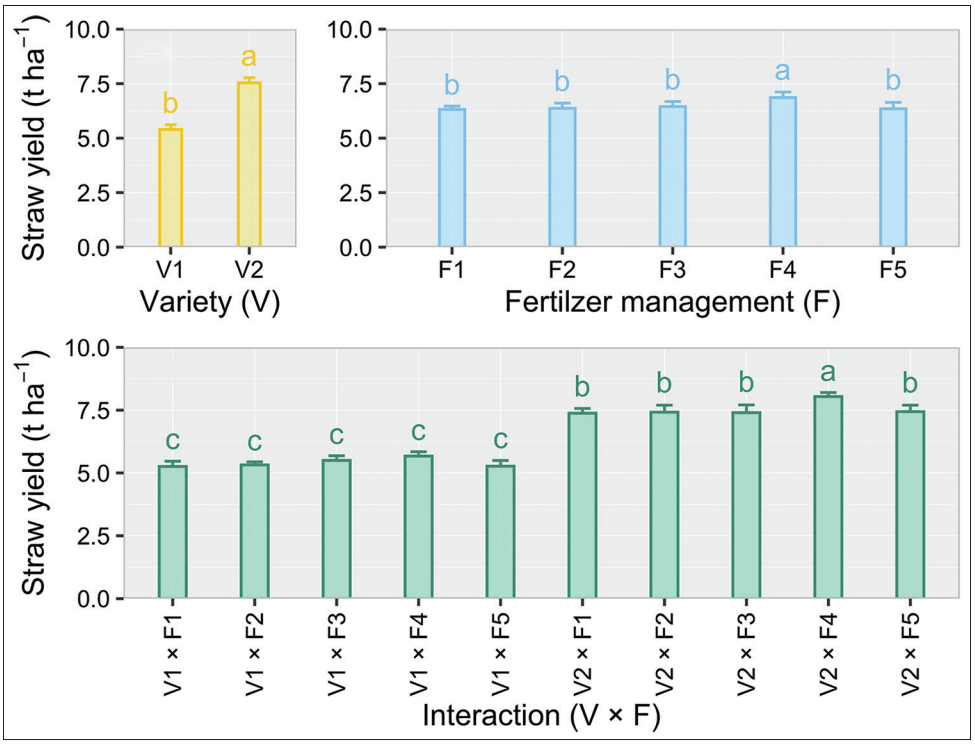

Figure 2: Effect of variety, fertilizer management and their interaction on the straw yield of *Boro* rice. V_1 - BRRI dhan28, V_2 - BRRI dhan89, F_1 - Recommended dose of fertilizers (RDF), F_2 - RDF + foliar application of 1% P at panicle initiation stage, F_3 - RDF + foliar application of 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_4 - RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage, F_5 - 75% RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage

panicle initiation stage) which was identical to F_4 (48.88%) (Table 2). The maximum result (49.90%) was counted from BRRI dhan89 with F_4 (RDF + foliar supplementation of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) which was identical to V_2F_5 (49.74%), V_2F_3 (49.67%), V_2F_2 (49.61%), V_2F_1 (49.41%) and V_1F_5 (49.17%). The minimum harvest index (47.77%) was calculated from BRRI dhan28 with F_3 (RDF) which was identical to V_1F_1 (48.66%), V_1F_2 (48.50%), V_1F_3 (47.77%) and V_1F_4 (47.86%) (Table 4).

DISCUSSION

In our investigation, it was observed that the *Boro* rice yield and associated characteristics were notably affected by the utilization of foliar phosphorus and zinc fertilizers in conjunction with the adoption of diverse varieties. BRRI dhan89 exhibited superior grain yields and related characteristics including plant height, total tillers $hill^{-1}$, effective tillers $hill^{-1}$, panicle length, grains $panicle^{-1}$, 1000 grain weight, straw yield, biological yield and harvest index when compared to BRRI dhan28. Conversely, BRRI dhan28 recorded the highest non-effective tillers $hill^{-1}$ and sterile spikelets $panicle^{-1}$ (Tables 1, 2 & Figures 1, 2).

The influence of rice variety on yield contributing characteristics in rice production is noteworthy as various rice cultivars demonstrate distinct traits that directly impact overall yield. According to Sarkar *et al.* (2014) and Akter *et al.* (2018), different rice varieties exhibit variable effects on plant height. Furthermore, Jisan *et al.* (2014) and Soltani and Molki (2022) observed variations in the number of effective tillers $hill^{-1}$ and panicle length which were attributed to differences in rice varieties. Their research highlighted the diverse impact of various rice varieties on the number of effective tillers $hill^{-1}$. Comparable findings concerning other yield components were reported elsewhere (Zoz *et al.*, 2012; Jamshid *et al.*, 2012; Sultana *et al.*, 2016; Chowdhury *et al.*, 2016; Sarker *et al.*, 2021; Roy *et al.*, 2024).

With foliar application, RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage resulted maximum plant height, number of total tillers $hill^{-1}$, effective tillers $hill^{-1}$, panicle length, grains $panicle^{-1}$, 1000 grain weight, grain yield, straw yield and biological yield where the highest harvest index was calculated with RDF + foliar application of 1% P (Tables 1, 2 & Figures 1, 2). Phosphorus and Zinc are vital elements, serving either as metallic constituents within enzymes or as cofactors with functional, structural or regulatory roles for numerous enzymes. This research identified a collaborative impact of phosphorus and zinc in augmenting the height of rice plants. In a study by Sultana *et al.* (2016), comparable findings were observed, indicating that the greatest plant height was documented when 0.5% P and 0.6% Zn were applied through foliar spraying on the leaves. Zoz *et al.* (2012) discovered that foliar application of zinc had minimal impact on agronomic conditions and the traits associated with the effective number of tillers $plant^{-1}$. Additionally, Rafiullah *et al.* (2018) conducted an experiment that illustrated how foliar application of 1% phosphorus can enhance panicle length. Zeidan and Nofal (2002) found that zinc application significantly increases grain panicles per unit in contrast to the control. Additionally, the application of a foliar fertilizer containing 0.5% zinc resulted in the most significant enhancements in the majority of the examined characteristics. Sultana *et al.* (2016) observed that the highest panicle count was attained by applying a foliar mixture containing 2% zinc and 1% phosphorus. Jamshid *et al.* (2012) conducted experiments with the foliar application of fertilizers which showed significant increases in 1000-seed weight, grain yield and biological yield. Ghoneim (2016) conducted an experiment indicating that foliar application of 1% P can improve straw yield.

The interaction between phosphorus and zinc fertilizers, along with the different varieties significantly affected of *Boro* rice yield. BRRI dhan89 when applied with RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ demonstrated the highest plant height, number of total tillers $hill^{-1}$, number of effective tillers $hill^{-1}$, panicle length, grains $panicle^{-1}$, 1000-grain weight, grain yields, straw yields, biological yield and harvest index. Conversely, the maximum number of non-effective tillers $hill^{-1}$ and sterile spikelets $panicle^{-1}$ were observed in BRRI dhan89 with 75% RDF and foliar application of 1% P and 0.5% $ZnSO_4.7H_2O$ at the panicle initiation stage as well as in BRRI dhan28 with RDF (Tables 3, 4 & Figures 1, 2). Soltani *et al.* (2022) conducted investigations to explore the influence of foliar supplementation of zinc and phosphorus on grain yield and its components. Their results demonstrated that applying zinc and phosphorus with foliar supplementations resulted in a noteworthy rise of approximately 10% in rice straw and 7% in biological yield. These findings indicate that the foliar supplementation of phosphorus and zinc holds promise in augmenting rice yield components and physiological attributes to increase in yield. Mandal and Ghosh (2021) reported substantial enhancements in total tillers $hill^{-1}$ with the foliar supplementation of 1% P and 1% Zn. Additionally, Rafiullah *et al.* (2018) conducted a study emphasizing the positive impact of foliar supplementation of phosphorus on panicle length. Latif *et al.* (2020) observed significant variations in 1000-grain weight which they attributed to the yield of different rice varieties. In a separate study, Boonchuay *et al.* (2013) stated that involving the foliar supplementation of fertilizers specifically 1% P and 0.4% Zn revealed notable increases in biological yield.

CONCLUSION

The present study demonstrated the significant influence of both variety and foliar supplementation on crucial yield parameters of *Boro* rice. BRRI dhan89 fertilized with F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) treatment resulted in the maximum grain yield (8.01 t ha^{-1}) and straw yield (8.04 t ha^{-1}). In contrast, the minimum grain yield (4.98t ha^{-1}) and straw yield (5.26 t ha^{-1}) resulted from BRRI dhan28 cultivar under F_1 (RDF) treatment. Based on the results it was revealed that the variety BRRI dhan89 with F_4 (RDF + foliar application of both 1% P and 0.5% $ZnSO_4.7H_2O$ at panicle initiation stage) treatment exhibited the superior impacts on yield and its components.

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