Fundamental and Applied Agriculture
Vol. 7(2), pp. 121–130: 2022
doi: 10.5455/faa.87165

Agronomy | Original Article

Comparative performance and economics of different zinc application approaches in Boro rice

Sumaiya Afrin[1], Md Parvez Anwar [1*], Md Rashedur Rahman[2], Ahmed Khairul Hasan [2], Farzana Bintay Forhad[1], Sabina Yeasmin [1], A K M Mominul Islam [1], Md Sultan Uddin Bhuiya[2,3]

[1]Agro Innovation Laboratory, Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh
[2]Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh
[3]University Grants Commission, Agargaon Administrative Area, Dhaka 1207, Bangladesh

Article Information

Article History
Submitted: 31 May 2022
Accepted: 19 Jun 2022
First online: 30 Jun 2022

Academic Editor
Md Harun Or Rashid
mhrashid@bau.edu.bd

**Corresponding Author*
Md Parvez Anwar
parvezanwar@bau.edu.bd

Abstract

Zinc deficiency is now very common in Bangladesh causing significant yield losses of different crops including rice. Due to zinc and other micronutrient deficiencies the high yielding rice varieties fail to produce their potential yield even under good management practices. Although many farmers have started applying zinc fertilizer they are not aware of proper dose and application method. Therefore, in many cases farmers are applying zinc fertilizers indiscriminately without considering the efficacy and economic output. Keeping those in mind the proposed study bears huge importance to elucidate and enrich the present state of knowledge on zinc fertilization in rice for ensuring food and nutritional security of Bangladesh in a sustainable way. An experiment was therefore conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh during the period from December 2020 to May 2021 to investigate the effects of different doses of Zn applied through soil, root soaking and foliar on rice growth and yield and their economics in Boro seasons following a randomized complete block design with three replications. Two Boro rice varieties (BRRI dhan58 and Hira Dhan-1) and seven different zinc application approaches (including soil application, root dipping and foliar spray of zinc with different dose/concentration) were considered as treatments. Hybrid variety Hira Dhan-1 performed better than BRRI dhan58. Application of zinc resulted in better crop growth and higher yield. Soil application appeared as the most efficient approach. Grain yield increased over control due to zinc application ranged from 5.1 to 14.7%. Present study confirms the necessity of zinc fertilizer application for increasing Boro rice yield. Among the different application approaches, soil application was found most effective and foliar spray was least effective. Although soil application of $ZnSO_4$ @ 10 kg ha^{-1} produced the highest yield, application of $ZnSO_4$ @ 5 kg ha^{-1} was the most economic one. Hybrid rice Hira Dhan-1 out yielded high yielding inbred variety BRRI dhan58. Therefore, it is recommended to cultivate hybrid rice in Boro season with soil application of $ZnSO_4$ @ 5 kg ha^{-1} for higher yield and better economic return.

Keywords: Foliar feeding, root dipping, soil application, zinc fertilizer, Boro rice

Cite this article: Afrin S, Anwar MP, Rahman MR, Hasan AK, Forhad FB, Yeasmin S, Islam AKMM, Bhuiya MSU. 2022. Comparative performance and economics of different zinc application approaches in Boro rice. Fundamental and Applied Agriculture 7(2): 121–130. doi: 10.5455/faa.87165

1 Introduction

According to a recent report of United States Department of Agriculture, Bangladesh's total rice area and production levels in 2019-20 (May-April) are expected to increase slightly to 11.8 hectares and 35.3 million metric tons respectively of which Boro rice accounted for 53.8 percent, assuming good weather and higher yields in the market year (2019-2020). As per the USDA data, with production of 3.6 crore tonnes of rice Bangladesh stands in third position globally in rice production after China and India (USDA 2019-2020). The demand of rice in Bangladesh is increasing day by day due to ever increasing population. In recent years, huge pressure has been exerted on soil resource to ensure food security for its ever increasing population. Rice is the staple food for about 156 million people of the country. The population growth rate is 2 million per year, and if the population increases at this rate, the total population will reach 238 million by 2050. An increase in total rice production is required to feed this ever-increasing population. At the same time, the total cultivable land is decreasing at a rate of more than 1% per year owing to the construction of industries, factories, houses, roads, and highways. In 1983-84, the cropping intensity of the country was 171% whereas it was 191% in 2018 (Parvin et al., 2018). Increasing cropping intensity and cultivation of HYV are major reason of nutrient depletion from soil. Furthermore soil micronutrient deficiency has become another threat to rice production. Under this context increasing rice production is challenging.

Micronutrients are important for crop plant growth. As a result of the degradation of soil fertility over time, soil micronutrient shortage has developed in Bangladesh. Zinc insufficiency is the most deficient micronutrient in soils globally (Cakmak, 2002; Shivay et al., 2007) and more than 30% of soils have low Zn availability (Rana and Kashif, 2014). Zinc is a micronutrient element whose normal concentration range is 25 to 150 ppm in plants. Deficiencies of Zn are usually associated with concentrations of less than 20 ppm, and toxicities will occur when the Zn leaf concentration exceeds 400 ppm (Tisdale et al., 1997). Zinc deficiency causes multiple symptoms like brown blotches and streaks on leaves, plant remain stunted and may die in severe cases. Zn is also an essential mineral nutrient for human beings in addition to being essential to plants. It is estimated that 1/3 of the world population is affected by Zn deficiency that is associated with low dietary intake. Zinc deficiency has been linked to major health problems in humans, particularly in children, including delays in physical growth, immune system function, and learning ability, as well as DNA damage and cancer formation (Ho et al., 2003; Black et al., 2008). As a result, increasing Zn concentration in stable food crops is a significant humanitarian concern.

Zinc deficiency has been noticed in calcareous soils of the Gangetic Floodplain, continuously wet soils in irrigated areas, soils with high organic matter content, like peat soils, high pH saline soils and light colored Piedmont Plain soils. Zinc insufficiency resulted in lower yields and Zn malnutrition in individuals in regions where rice was consumed heavily (Tiong et al., 2013). Zn also is an important component of numerous enzymes and regulates a number of biochemical processes in plants that are necessary for growth (IRRI, 2000). Plants require zinc for protein synthesis and gene expression (Cakmak, 2002; Broadley et al., 2007). Zn is required for the structural and functional integrity of around 10% of proteins in biological systems (Andreini et al., 2006). More than 300 enzymes require this element as a cofactor, according to research (Coleman 1998). Zinc also plays a key role in Reactive oxygen species (ROS) detoxification in plant cells (Broadley et al., 2007). Zinc is a costly fertilizer, thus it must be applied in a way that maximizes Zn availability and efficiency. The most common zinc application approach is soil application, but recently foliar application and root dipping are also becoming popular for their better efficacy and economics (Khan et al., 2008; Karim et al., 2012). Therefore, it is very important to recognize the most effective and economic zinc application approach for rice. But, research findings on zinc application approach are meagre especially under Bangladesh conditions. The present research work was therefore undertaken to evaluate the effect of different methods of Zn application on growth and yield of Boro rice, and to find out the most suitable method of Zn application for higher productivity and profitability of Boro rice.

2 Materials and Methods

2.1 Experimental duration and site

The experiment was conducted during the period from December 2019 to May 2020 at the Agronomy Field Laboratory, Department of Agronomy, Bangladesh Agricultural University, Mymensingh. The experimental field was located at 24°43′11.1″N, 90°25′42.2″E and at an altitude of 18 meter above the sea level. The experimental area belongs to the non-calcareous dark grey soil under Agro-ecological Zone of the Old Brahmaputra Floodplain (AEZ-9). The land was medium high and well drained with silt-loam texture. The soil of the experimental field was more or less neutral in reaction (pH 6.7), low in organic matter content (1.29%) and the general fertility level of the soil was low (1% total N, 26 ppm available P and 0.14 me % exchangeable K). The experimental area was located under the subtropical climate, which is specialized by moderately high temperature and heavy rainfall during April to September and low rainfall with moderately low temperature during October to March. The monthly values of maximum, minimum and average temperature (°C), relative humidity (%), monthly total rainfall (mm) and sunshine (hour) received at the experimental site during the study period were 29.0 °C, 15.6 °C, 22.3 °C, 80.3%, 96.7 mm, and 173.6 h, respectively.

2.2 Experimental treatments and design

The experiment comprised two factors namely, variety and zinc application approach. Two Boro rice varieties included (i) BRRI dhan58 and (ii) Hira Dhan-1. While seven zinc application approaches were (i) control (no zinc application), (ii) root dipping @ 0.5% $ZnSO_4$, (iii) root dipping @ 1% $ZnSO_4$, (iv) soil application @ 5 kg $ZnSO_4$ ha^{-1}, (v) soil application @ 10 kg $ZnSO_4$ ha^{-1}, (vi) foliar spray @ 0.5% $ZnSO_4$, and (vii) foliar spray @ 1% $ZnSO_4$. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Thus, total number of plot was 54. Each plot size was 4 m × 2.5 m.

2.3 Plant materials

BRRI dhan58 and Hira Dhan-1 were used as plant materials. BRRI dhan58, a high yielding variety of Boro rice was developed by the Bangladesh Rice Research Institute (BRRI). This variety was developed by tissue culture of cultivar BRRI dhan29 and approved by National Seed Board in 2012. The cultivar BRRI dhan58 matures in 150- 155 days. It attains a height of 100 -105 cm at maturity. The grain is medium slender and white in color. The variety gives a grain yield of 7-7.5 t ha^{-1}. Hira Dhan-1 is a hybrid variety. Presently rice hybrid has positive acceptance in the country with most cultivars from china and a national rice hybrid only for Boro season. Hira Dhan-1 is originated from china and imported in our country by supreme seed company Ltd. This variety was approved by National Seed Board in 2001. This cultivar matures in 140-145 days. The plant is medium tall, do not wilt and is hail tolerant. The variety gives a grain yield of 8 t ha^{-1}.

2.4 Crop husbandry

Seeds of BRRI dhan58 were obtained from the Agronomy Field Laboratory of Bangladesh Agricultural University, Mymensingh. Seeds of Hira Dhan-1 were collected from the dealer of the local market. Healthy seeds were placed in water bucket for 24 h and then kept tightly in gunny bags. The seeds started sprouting after 48 h. After 72 hours seeds were sown in the nursery bed. During first week of December the nursery beds were prepared by puddling with repeated ploughing followed by laddering. Sprouted seeds were sown in raised nursery bed of 1.0 m length and 1.0 m width. The experimental land was prepared by a power tiller 10 days before transplanting. It was then puddled well with the help of a country plough to make the soil nearly ready for transplanting. Weeds and stubbles were removed and the field was then leveled by laddering. Well decomposed compost was applied @ 5 t ha^{-1} before final land preparation. The field was fertilized with 200 kg, 120 kg, 100 kg and 70 kg ha^{-1} of urea, triple superphosphate (TSP), muriate of potash (MoP), and gypsum, respectively. The full doses of TSP, MoP and gypsum were applied before transplanting. Urea was top dressed in three equal splits, at 15, 30 and 45 days after transplanting (DAT). Zinc was applied according to the treatment. When seedlings were uprooted for transplanting, seedling's roots were dipped into zinc solution of two concentrations (0.5% and 1% $ZnSO_4$) for 24 hrs. Soil application of $ZnSO_4$ was done 10 days after transplanting and foliar spray was done at the time of panicle initiation. Forty days old seedlings were transplanted in the well prepared puddled field on 20 January 2020 at the rate of three seedlings hill^{-1} maintaining row and hill distance of 25 cm and l5 cm, respectively. After one week of transplantation, seedlings of some of the hills died off and were replaced by gap filling with healthy seedlings by planting same aged seedlings. Weeding was done twice manually. First hand weeding was conducted at 20 days after transplanting and the second one is at 20 days at the first weeding. Irrigation water was supplied to each plot according to the need. All the plots were kept irrigated maintaining 3-5 cm stagnant water throughout the entire period. The field was finally dried out 15 days before harvesting. There were some incidence of insects specially stem borer and brown plant hopper which was controlled by spraying carbotaf 5G @ 2 mL L^{-1} and regent 3GR @ 2 mL L^{-1}.

2.5 Sampling, harvesting and processing

The crop was harvested at full maturity. This was the time when about 80% of the seeds became golden yellow in color. Five hills (excluding border hills) were randomly selected in each plot and uprooted before harvesting for recording the necessary data on various plant characters. The crops were harvested between 25 May to 30 May at ripening stage from each plot manually to record the yields of grain and straw. The harvested crop of each plot was separately bundled, properly tagged and then brought to the threshing floor. The crops were threshed manually. Grains were sun dried and cleaned. Straws were also sun dried properly. Finally, grain yield was adjusted to 14% moisture and converted to ton per hectare.

2.6 Statistical analysis

The recorded data were compiled and tabulated for statistical analysis. Analysis of variance was done with the help of computer package MSTAT. Collected data were analyzed using the "Analysis of variance" technique and the significance of the mean differences was adjudged by Duncan's Multiple Range Test (DMRT).

3 Results

3.1 Plant height

Plant height of rice was significant at 30 DAT and at 60 DAT but not significant at 45, 75, 80 DAT and at harvest for the variety. At both 30 and 60 DAT, Hira Dhan-1 produced taller plants than BRRI dhan58. At all other sampling dates, Hira Dhan-1 also produced numerically taller plants than BRRI dhan58 (Table 1). Effect of different Zn application approaches on plant height of rice was significant at 30, 45, 60 DAT but not at 75 and 80 DAT and at harvest. At 30 DAT, highest plant height of 52.25 cm was obtained when $ZnSO_4$ was applied @ 10 kg ha^{-1} as soil application statistically followed by 5 kg $ZnSO_4$ ha^{-1} as soil application. Root dipping and foliar spray did not produce any increase in plant height compared to control (Table 2). At 45 DAT, zinc applied by different methods of application significantly increased plant height over control. Maximum plant height of 70.36 cm was obtained when $ZnSO_4$ applied @ 10 kg ha^{-1} as soil application followed by 5 kg $ZnSO_4$ ha^{-1} as soil application. Root dipping with 1% $ZnSO_4$ solution, root dipping with 0.5% $ZnSO_4$ solution, foliar spray with 1% $ZnSO_4$ solution, foliar spray with 0.5% $ZnSO_4$ solution produced statistically similar plant height which was higher than control. Minimum plant height of 56.88 cm was obtained from control (Table 2). At 60 DAT, zinc applied by different methods of application also significantly increased plant height over control. Maximum plant height of 88.56 cm was obtained when $ZnSO_4$ applied @ 5 kg ha^{-1} as soil application followed by root dipping with 1% $ZnSO_4$ solution. Root dipping with 0.5% $ZnSO_4$ solution, foliar spray with 1% $ZnSO_4$ solution, foliar spray with 0.5% $ZnSO_4$ solution produced statistically similar plant height which was higher than control. Minimum plant height of 76.48 cm was obtained from control (Table 2). The interaction of variety and Zn application approaches did not significantly affect the plant height of rice at any growth stage (data not presented).

3.2 Tillering ability

Number of tillers hill^{-1} was significantly influenced by variety at 1% probability. At all the growth stages, Hira Dhan-1 produced more tiller than BRRI dhan58 (Table 3).Effect of different Zn application approaches on number of tillers hill^{-1} was significant at 30, 45, 60, 80 DAT but not significant at 75 DAT and at harvest. At 30 DAT, highest tiller number hill^{-1} (8.28) was recorded when $ZnSO_4$ was applied @ 10 kg ha^{-1} as soil application statistically followed by 5 kg $ZnSO_4$ ha^{-1} as soil application. Root dipping and foliar spray produced statistically similar number of tiller hill^{-1} which was higher than control. Lowest tiller number hill^{-1} (5.77) was recorded at control (Table 4). At 45 DAT, zinc applied by different methods of application significantly increased number of tiller hill^{-1} control. Maximum tiller number hill^{-1} (11.40) was obtained when $ZnSO_4$ was applied @ 10 kg ha^{-1} as soil application statistically followed by 5 kg $ZnSO_4$ ha^{-1}. Root dipping with 1% $ZnSO_4$ solution or 0.5% $ZnSO_4$ solution or foliar spray with 1% $ZnSO_4$ solution produced statistically similar number of tiller hill^{-1} which was higher than control. Foliar spray with 0.5%% $ZnSO_4$ solution did not increase tiller number compared to control (Table 4). At 60 DAT, zinc applied by different methods of application also significantly increased number of tillers hill^{-1} over control. Maximum tiller number hill^{-1} (14.43) was obtained when $ZnSO_4$ was applied @ 10 kg ha^{-1}as soil application statistically followed by 5 kg $ZnSO_4$ ha^{-1} as soil application. Root dipping with 1% $ZnSO_4$ solution and root dipping with 0.5% $ZnSO_4$ solution produced statistically similar number of tiller hill^{-1}. Foliar spray with 0.5% $ZnSO_4$ solution did not favor tillering any increase compared to control. Minimum tiller number hill^{-1} (12.10) was obtained from control (Table 5). At 80 DAT, zinc applied by different methods of application also significantly increased number of tiller hill^{-1} over control. Maximum tiller number hill^{-1} (16.37) was obtained when $ZnSO_4$ was applied @ 10 kg ha^{-1} as soil application statistically followed by 5 kg $ZnSO_4$ ha^{-1} as soil application. Foliar spray and root produce statistically similar number of tiller hill^{-1} which was higher than control. Minimum tiller number hill^{-1} (13.87) was obtained from control (Table 4). The interaction of variety and Zn application approaches did not significantly affect the number of tillers hill^{-1} rice at any growth stage (data not presented).

3.3 Number of effective tillers hill^{-1}

Number of effective tillers hill^{-1} was significantly influenced by variety at 1% probability. Results showed that Hira Dhan-1 was found more productive than BRRI dhan58 in effective tiller production. Hira Dhan-1 produced 3 more tillers than BRRI dhan58 (Table 5). Zn application approaches significantly affected the number of effective tillers hill^{-1} of Boro rice. Results showed that highest number of effective tillers hill^{-1} 13.70 was recorded when $ZnSO_4$ was applied @ 10 kg ha^{-1}as soil application statistically followed by 5 kg $ZnSO_4$ ha^{-1} applied to soil. Root dipping with 1% $ZnSO_4$ solution, foliar spray with % $ZnSO_4$ solution, foliar spray with 0.5% $ZnSO_4$ solution and root dip-

Table 1. Effect of variety on plant height of Boro rice at different days after transplanting

Variety	30 DAT	45 DAT	60 DAT	75 DAT	80 DAT	At harvest
BRRI dhan58	44.18 b	61.83	78.68 b	82.84	101.22	102.87
Hira Dhan-1	47.13 a	63.61	86.82 a	84.21	104.56	106.86
$S\bar{x}$	0.87	0.73	1.28	1.75	2.25	1.82
Level of significance	*	NS	**	NS	NS	NS
CV (%)	8.73	5.33	7.04	8.58	10	7.84

DAT = days after transplanting; ** = Significant at 1% level of probability, * =Significant at 5% level of probability, NS = Non-significant. In a column figures with same letter or without letter do not differ significantly whereas figure with dissimilar letter differ significantly as per DMRT.

Table 2. Effect of Zn application approach on plant height of Boro rice at different days after transplanting

Zn application approaches	30 DAT	45 DAT	60 DAT	75 DAT	80 DAT	At harvest
Control	41.71 c	56.88 c	76.48 d	80.1	88.54	100.86
Root dipping @ 0.5% $ZnSO_4$	44.64 c	60.88 bc	81.41 cd	82.76	103.01	105.62
Root dipping @ 1% $ZnSO_4$	46.37 bc	63.16 b	84.62 b	84.1	103.4	106.37
Soil application @ 5 kg $ZnSO_4$ ha^{-1}	50.81 ab	68.48 a	88.56 a	86.57	104.77	106.46
Soil application @10 kg ZnSO4 ha^{-1}	52.25 a	70.36 a	82.18 bc	88.27	106.66	108.26
Foliar spray @ 0.5% $ZnSO_4$	42.04 c	58.08 bc	78.04 cd	80.53	101.44	102.33
Foliar spray @ 1% $ZnSO_4$	41.65 c	60.06 bc	78.84 cd	81.35	102.4	103.74
$S\bar{x}$	1.81	1.36	2.38	3.27	4.2	3.4
Level of significance	**	**	**	NS	NS	NS
CV (%)	8.73	5.33	7.04	8.58	10	7.84

DAT = days after transplanting; ** = Significant at 1% level of probability, NS = Non-significant. In a column figures with same letter or without letter do not differ significantly whereas figure with dissimilar letter differ significantly as per DMRT.

Table 3. : Effect of variety on number of total tillers $hill^{1}$ of Boro rice at different days after transplanting

Variety	30 DAT	45 DAT	60 DAT	75 DAT	80 DAT	At harvest
BRRI dhan58	5.33 b	8.51 b	11.24 b	13.30 b	13.23 b	11.80 b
Hira Dhan-1	8.35 a	11.70 a	14.82 a	16.62 a	16.48 a	15.25 a
$S\bar{x}$	0.157	0.201	0.284	0.278	0.218	0.242
Level of significance	**	**	**	**	**	**
CV (%)	10.58	8.11	8.88	8.54	6.76	8.2

DAT = days after transplanting; ** = Significant at 1% level of probability

Table 4. Effect of zinc application approach on number of total tillers hill1 of Boro rice at different days after transplanting

Zn application approaches	30 DAT	45 DAT	60 DAT	75 DAT	80 DAT	At harvest
Control	5.77 c	8.83 c	12.10 c	14.08	13.87 c	12.77
Root dipping @ 0.5% $ZnSO_4$	6.58 bc	8.85 bc	12.87 abc	14.48	14.52 bc	13.23
Root dipping @ 1% $ZnSO_4$	6.82 b	10.10 bc	13.27 abc	14.88	14.67 bc	13.57
Soil application @ 5 kg $ZnSO_4$ ha^{-1}	7.87 a	11.02 ab	14.00 ab	15.65	15.37 ab	14.08
Soil application @10 kg ZnSO4 ha^{-1}	8.28 a	11.40 a	14.43 a	16.17	16.37 a	14.5
Foliar spray @ 0.5% $ZnSO_4$	6.25 bc	8.53 c	12.18 c	14.52	14.32 bc	13.27
Foliar spray @ 1% $ZnSO_4$	6.22 bc	8.80 bc	12.37 bc	14.83	14.77 bc	13.58
$S\bar{x}$	0.285	0.376	0.531	0.522	0.41	0.454
Level of significance	**	**	*	NS	**	NS
CV (%)	10.58	8.11	8.88	8.54	6.76	8.2

DAT = days after transplanting; ** = Significant at 1% level of probability, * =Significant at 5% level of probability, NS = Non-significant. In a column figures with same letter or without letter do not differ significantly whereas figure with dissimilar letter differ significantly as per DMRT.

Table 5. Effect of variety on yield contributing characters and yield of Boro rice

Variety	Effective tillers $hill^{-1}$	Grains $panicle^{-1}$	1000-grain weight (g)	Sterility (%)	Grain yield (t ha^{-1})
BRRI dhan58	10.80 b	110.85 b	24.08 b	13.14	6.11 b
Hira Dhan-1	13.81 a	131.68 a	27.41 a	12.21	8.41 a
$S\bar{x}$	0.182	2.03	0.124	0.378	0.02
Level of significance	**	**	**	NS	**
CV (%)	6.77	7.66	2.21	13.73	1.24

** = Significant at 1% level of probability, NS = Non-significant. In a column figures with same letter or without letter do not differ significantly whereas figure with dissimilar letter differ significantly as per DMRT.

Table 6. Effect of zinc application approach on yield contributing characters and yield of Boro rice

Zn application approaches	Effective tillers $hill^{-1}$	Grains $panicle^{-1}$	1000-grain weight (g)	Sterility (%)	Grain yield (t ha^{-1})
Control	10.85 c	113.3c	25.57	4	6.80 e
Root dipping @ 0.5% $ZnSO_4$	12.02 b	122.0abc	25.65	12.73	7.03 d
Root dipping @ 1% $ZnSO_4$	12.50 b	122.6abc	25.78	12.52	7.18 c
Soil application @ 5 kg $ZnSO_4$ ha^{-1}	12.80 ab	127.2ab	26.02	12.58	7.63 b
Soil application @10 kg ZnSO4 ha^{-1}	13.70 a	133.3a	25.8	12.38	7.80 a
Foliar spray @ 0.5% $ZnSO_4$	12.07 b	113.8c	25.57	12.1	7.20 c
Foliar spray @ 1% $ZnSO_4$	12.37 b	116.6bc	25.78	12.42	7.18 c
$S\bar{x}$	0.341	3.78	0.232	0.71	0.037
Level of significance	**	**	NS	NS	**
CV (%)	6.77	7.66	2.21	13.73	1.24

DAT = days after transplanting; ** = Significant at 1% level of probability, NS = Non-significant. In a column figures with same letter or without letter do not differ significantly whereas figure with dissimilar letter differ significantly as per DMRT.

ping with 0.5% $ZnSO_4$ solution produced statistically similar number of effective tillers hill^{-1}. No application of $ZnSO_4$ (Control) produced the lowest number of effective tillers hill^{-1} (Table 6).The interaction of variety and Zn application approaches did not significantly affect the number of effective tillers hill^{-1} (data not presented).

3.4 Grains panicle^{-1}

Number of grains panicle^{-1} was significantly influenced by variety at 1% probability. Results showed that Hira Dhan-1 produced 21 more grains panicle^{-1} than BRRI dhan58 (Table 5). Zn application approaches significantly affected number of grains panicle^{-1} of Boro rice. Results showed that highest number of grains panicle^{-1} (133.37) was recorded when $ZnSO_4$ was applied @ 10 kg ha^{-1}as soil application statistically followed by 5 kg $ZnSO_4$ ha^{-1} applied to soil. Root dipping with 1% $ZnSO_4$ solution and root dipping with 0.5% $ZnSO_4$ solution produce similar number of grains panicle^{-1}. Foliar spray did not increase in grain number compared to control (Table 6). The interaction of variety and Zn application approach did not significantly affect the number of grains panicle^{-1} (data not presented).

3.5 1000-grain weight

The 1000 grain weight of Boro rice was significantly affected by variety at 1% probability. As per genetical character, Hira Dhan-1 produced bigger size grains compared to those of BRRI dhan58. Thus the 1000 grain weight of Hira Dhan-1 was higher than that of BRRI dhan58 (Table 5). Zn application approaches did not significantly affect 1000 grain weight of Boro rice (Table 5). The interaction between variety and Zn application approaches did not significantly affect 1000 grain weight of Boro rice (data not presented).

3.6 Sterility %

Sterility % of Boro rice was not significantly affected by variety. But numerically BRRI dhan58 showed higher sterility % than Hira Dhan-1 (Table 5). Sterility % of Boro rice was not significantly affected by different Zn application approaches. But application of Zn in any form numerically reduced sterility % in Boro rice (Table 6).The interaction between variety and Zn application approaches did not significantly affect sterility percentage of Boro rice (data not presented).

3.7 Grain yield

Grain yield of rice was significantly affected by variety at 1% probability level. As expected, Hybrid variety Hira Dhan-1 was more productive than high yielding inbred variety BRRI dhan58. As recorded, Hira Dhan-1 produce 2.3 ton more yield per hectare than BRRI dhan58 (Table 5). Zn application approaches exerted significant effect on grain yield of Boro rice. The result showed that maximum grain yield (7.80 t ha^{-1}) was found when $ZnSO_4$ was applied @ 10 kg ha^{-1} as soil application closely followed by 5 kg $ZnSO_4$ ha^{-1} applied to soil. Root dipping and foliar spray of Zn resulted in lower grain yield compared to soil Zn application (control). Control produced lowest grain yield (Table 6).The interaction effect of variety and Zn application approaches significantly affected the grain yield of rice. The result showed that maximum grain yield (8.80 t ha^{-1}) was found when Hira Dhan-1 treated with $ZnSO_4$ @ 10 kg ha^{-1} as soil application statistically followed by 5 kg $ZnSO_4$ ha^{-1} as soil application. In general, Hira Dhan-1 performed better than BRRI dhan58 irrespective of Zn application approaches. Minimum grain yield 5.73 t ha^{-1} was found in BRRI dhan58 under control or root dipping with 0.5% $ZnSO_4$ (Fig. 1).

3.8 Economics of Zn application

Irrespective of application approaches, zinc fertilization was found more economic than control for either variety. The maximum gross return and net return were recorded in Hira Dhan-1 treated with 10 kg ha^{-1} $ZnSO_4$ applied to the soil, while application of no zinc (Control) resulted in the lowest gross and net return. The maximum benefit cost ratio was calculated when Hira Dhan-1 was treated with 5 kg ha^{-1} $ZnSO_4$ applied in soil. Cultivation of Hira Dhan-1 was found more remunerative than BRRI dhan58 (Table 7).

4 Discussion

Zinc is an essential micronutrient important for plant functions, such as growth hormone production and internode elongation and thus affects plant stature and tillering ability. Deficiency of Zn show stunted growth. The result of this study showed that zinc application significantly increased the plant height over control which might be attributed to the adequate supply of zinc which accelerated the enzymatic activity and auxin metabolism in plants. Similar results were also obtained by Maqsood et al. (1999) who reported that application of $ZnSO_4$ @ 15 kg Zn ha^{-1} through soil to rice crop significantly affected plant height. Begum et al. (2003) and Yoshida et al. (1970) also reported positive influence of zinc application on rice plant height. Tillering ability depends on crop variety and growing condition. The results of this study revealed that highest number of tillers hill^{-1} produced when Hira Dhan-1 was treated with $ZnSO_4$ @ 10 kg ha^{-1} as soil application. Khan et al. (2003) and Yaseen et al. (1999) reported similar results. Increase in number of tillers m^{-2} might be ascribed to

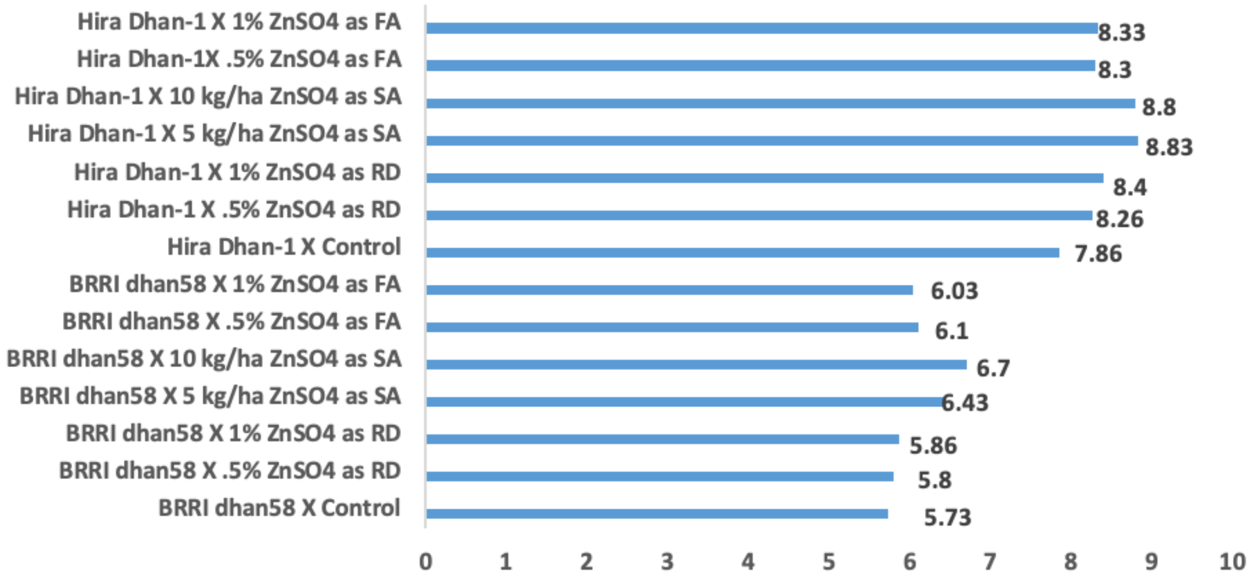

Figure 1. Interaction effect of variety and zinc application approach on yield Boro rice yield (t ha^{-1})

Table 7. Cost-benefit analysis of different zinc application approaches for BRRI dhan58 and Hira Dhan-1

V × Z interaction		TVC (Tk ha^{-1})	GR (Tk ha^{-1})	NR (Tk ha^{-1})	BCR
BRRI dhan58	Control	1,40,000	1,83,225	43,225	1.31
	Root dipping @ 0.5% $ZnSO_4$	1,41,000	1,89,950	48,950	1.35
	Root dipping @ 1% $ZnSO_4$	1,41, 500	1,92,000	50,500	1.36
	Soil application @ 5 kg $ZnSO_4$ ha^{-1}	1,41,250	2,05,450	64,200	1.45
	Soil application @10 kg ZnSO4 ha^{-1}	1,42,500	2,15,725	73,225	1.51
	Foliar spray @ 0.5% $ZnSO_4$	1,41,500	1,95,925	54,425	1.38
	Foliar spray @ 1% $ZnSO_4$	1,42,000	1,93,875	51,875	1.37
Hira Dhan-1	Control	1,40,000	2,53,450	1,13,450	1.81
	Root dipping @ 0.5% $ZnSO_4$	1,41,000	2,63,350	1,22,350	1.87
	Root dipping @ 1% $ZnSO_4$	1,41, 500	2,68,575	1,27,075	1.89
	Soil application @ 5 kg $ZnSO_4$ ha^{-1}	1,41,250	2,82,025	1,40,775	1.99
	Soil application @10 kg ZnSO4 ha^{-1}	1,42,500	2,84,075	1,41,575	1.98
	Foliar spray @ 0.5% $ZnSO_4$	1,41,500	2,65,775	1,24,275	1.88
	Foliar spray @ 1% $ZnSO_4$	1,42,000	2,66,150	1,24,150	1.87

$ZnSO_4$ = TK 250 kg^{-1}; Rough rice= TK 28 kg^{-1}; Straw= TK 3.75 kg^{-1}; Day labor= TK 500 day^{-1}, TVC= Total variable cost, GR= Gross return, NR= Net return, BCR = Benifit cost ratio adequate supply of zinc, which resulted in improvement of plant metabolic process and finally increased the crop growth. These results are in accordance with Naik and Das (2010) who reported that adequate supply of zinc produced more number of total and productive tillers per m^{-2}.

Grains panicle^{-1} is an important yield contributing parameter which greatly influences rice yield. In this study, zinc application significantly increased the number of grains panicle^{-1} over control as because Zn plays a significant role in enzyme activation, chlorophyll biosynthesis, pollen tube formation, pollen viability and starch utilization (Andreini et al., 2006). The highest grain panicle^{-1} was found when Zn applied as soil application. These findings are in line with the results of Maqsood et al. (1999) and Naik and Das (2010) who reported that with the application of zinc, grains panicle were increased. On the other hand, foliar application of Zn increased the total number of grains per panicle as reported by Karim et al. (2012) and Khan et al. (2008) due to higher availability. In this study, 1000-grain weight was not influenced by variety and different Zn application. Khan and Qasim (2007) found almost similar results. But increase in 1000 grain weight due to foliar application of Zn was also reported by Khan et al. (2008). The comparative increase in 1000-grain weight with the application of zinc might be due to more efficient participation of Zn in various metabolic processes (Asad and Rafique, 2000). In this study variety and all the zinc application approaches increased the grain yield significantly. Increase in grain yield might be due to continuous photosynthesis in leaf at the time of grain filling phase. Zinc might have greater role in plant physiology and improved photosynthesis. In case of control, the growth and development of plant were hampered due to non or less availability of zinc which resulted in poor performance of yield attributes and ultimately reduced grain yield. Similarly, Khan and Qasim (2007) stated that zinc application increased the grain yield significantly over control. Hybrid variety Hira Dhan-1 showed higher productivity than BRRI dhan58 which might be due to the higher yield potential of hybrid variety.

5 Conclusion

Hira Dhan-1 performed better than BRRI dhan58 and application of zinc increased rice yield. Soil application of Zn resulted in better performance compared to foliar spray and root dipping. Hybrid variety Hira Dhan-1 treated with $ZnSO_4$ applied @ 10 kg ha^{-1} as soil application was found as most yielding and application of $ZnSO_4$ @ 5 kg ha^{-1} was the most economic one.

Acknowledgments

The second author thankfully acknowledges the financial support provided by the Ministry of Science and Technology, Government of the People's Republic of Bangladesh for the project number: Project no: 39.00.0000.009.14.011.20-1331/42 BS under special allocation for science and technology, for the financial year 2020-2021. The authors also thankfully acknowledge the administrative and technical supports provided by Bangladesh Agricultural University Research Systems (BAURES) and Department of Agronomy during the implementation of the project.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Andreini C, Banci L, Bertini I, Rosato A. 2006. Zinc through the three domains of life. Journal of Proteome Research 5:3173–3178. doi: 10.1021/pr0603699.

Asad A, Rafique R. 2000. Effect of zinc, copper, iron, manganese and boron on the yield and yield components of wheat crop in tehsil peshawar. Pakistan Journal of Biological Sciences 3:1615–1620. doi: 10.3923/pjbs.2000.1615.1620.

Begum M, Noor M, Miah H, Basher MM. 2003. Effect of rate and method of zinc application on growth and yield of aus rice. Pakistan Journal of Biological Sciences 6:688–692. doi: 10.3923/pjbs.2003.688.692.

Black RE, Allen LH, Bhutta ZA, Caulfield LE, de Onis M, Ezzati M, Mathers C, Rivera J. 2008. Maternal and child undernutrition: global and regional exposures and health consequences. The Lancet 371:243–260. doi: 10.1016/s0140-6736(07)61690-0.

Broadley MR, White PJ, Hammond JP, Zelko I, Lux A. 2007. Zinc in plants. New Phytologist 173:677–702. doi: 10.1111/j.1469-8137.2007.01996.x.

Cakmak I. 2002. Plant nutrition research: Priorities to meet human needs for food in sustainable ways. In: Progress in Plant Nutrition: Plenary Lectures of the XIV International Plant Nutrition Colloquium. Springer Netherlands. doi: 10.1007/978-94-017-2789-1_1.

Ho E, Courtemanche C, Ames BN. 2003. Zinc deficiency induces oxidative DNA damage and increases P53 expression in human lung fibroblasts. The Journal of Nutrition 133:2543–2548. doi: 10.1093/jn/133.8.2543.

IRRI. 2000. Nutritional disorders and nutrient management in rice. International Rice Research Institute, Manila, Philippines.

Karim MR, Zhang YQ, Zhao RR, Chen XP, Zhang FS, Zou CQ. 2012. Alleviation of drought stress in winter wheat by late foliar application of zinc, boron, and manganese. Journal of Plant Nutrition and Soil Science 175:142–151. doi: 10.1002/jpln.201100141.

Khan M, Fuller M, Baloch F. 2008. Effect of soil applied zinc sulphate on wheat (*Triticum aestivum* L.) grown on a calcareous soil in Pakistan. Cereal Research Communications 36:571–582. doi: 10.1556/crc.36.2008.4.6.

Khan MU, Qasim M. 2007. Effect of zn fertilizer on rice grown in different soils of dera ismail khan. Sarhad Journal of Agriculture 23:1033.

Khan MU, Qasim M, Subhan M, Jamil M, Ahmad RD. 2003. Response of rice to different methods of zinc application in calcareous soil. Journal of Applied Sciences 3:524–529. doi: 10.3923/jas.2003.524.529.

Maqsood M, Irshad M, Wajid SA, Hussain A. 1999. Growth and yield response of Basmati-385 (*Oryza sativa* l.) to $ZnSO_4$ application. Pakistan Journal of Biological Sciences 2:1632–1633. doi: 10.3923/pjbs.1999.1632.1633.

Naik SK, Das DK. 2010. Evaluation of various zinc extractants in lowland rice soil under the influence of zinc sulfate and chelated zinc. Communications in Soil Science and Plant Analysis 41:122–134. doi: 10.1080/00103620903361674.

Parvin N, Khatun A, Quais M, Nasim M. 2018. Cropping pattern, intensity and diversity in Dhaka region. Bangladesh Rice Journal 21:123–141. doi: 10.3329/brj.v21i2.38200.

Rana WK, Kashif SR. 2014. Effect of different zinc sources and methods of application on rice yield and nutrients concentration in rice grain and straw. Journal of Environment and Agricultural Sciences 7:1–9.

Shivay YS, Kumar D, Prasad R, Ahlawat IPS. 2007. Relative yield and zinc uptake by rice from zinc sulphate and zinc oxide coatings onto urea. Nutrient Cycling in Agroecosystems 80:181–188. doi: 10.1007/s10705-007-9131-5.

Tiong J, McDonald GK, Genc Y, Pedas P, Hayes JE, Toubia J, Langridge P, Huang CY. 2013. H v ZIP 7 mediates zinc accumulation in barley (*Hordeum vulgare*) at moderately high zinc supply. New Phytologist 201:131–143. doi: 10.1111/nph.12468.

Tisdale LS, Nelson LW, Beaton DJ, Howlin LJ. 1997. Soil Fertility and Fertilizer. Prentice Hall, India.

Yaseen M, Hussain T, Hakeem A, SAhmad. 1999. Integrated nutrient use including zinc for rice. Pakistan Journal of Biological Sciences 2:614–616. doi: 10.3923/pjbs.1999.614.616.

Yoshida S, McLean GW, Shafi M, Mueller KE. 1970. Effects of different methods of zinc application on growth and yields of rice in a calcareous soil, West Pakistan. Soil Science and Plant Nutrition 16:147–149. doi: 10.1080/00380768.1970.10432832.

The Official Journal of the
Farm to Fork Foundation
ISSN: 2518–2021 (print)
ISSN: 2415–4474 (electronic)
http://www.f2ffoundation.org/faa