INFLUENCE OF ZINC APPLICATION METHODS ON GROWTH AND YIELD OF BORO RICE

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CERTIFICATE

This is to certify that the thesis entitled, **"INFLUENCE OF ZINC APPLICATION METHODS ON GROWTH AND YIELD OF BORO RICE"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRONOMY**, embodies the result of a piece of bonafide research work carried out by **MD. BABUL MIA, Registration No.12-04958** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated: June, 2018 **(Prof. Dr. A. K. M. Ruhul Amin)**

Place: Dhaka, Bangladesh **Supervisor**

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The author

INFLUENCE OF ZINC APPLICATION METHODS ON GROWTH AND YIELD OF BORO RICE

ABSTRACT

Zinc deficiency is widely spread in Banglabeshi paddy soils and has negative impact on national rice (*Oryza sativa* L.) production. A field experiment was conducted at the experimental plot of Sher-e-Bangla Agricultural University, Dhaka from December 2017 to May 2018 to evaluate the effects of different zinc application methods on growth and yield of boro rice. The experiment was consisted of two factors viz. - factor A. variety -3; (i) V_1 = BRRI dhan45; (ii) V_2 = BRRI dhan63; and (iii) V_3 = BRRI hybrid dhan3; and factor B. methods of Zn application 4; (i) F_0 = No zinc application; (ii) F_1 = Zn application through root soaking; (iii) F_2 = Zn application through foliar spray; (iv) F_3 = Zn application through soil application. The experiment was laid out following split-plot design with three replication where variety was assigned in main plot and zinc application methods in subplot. Data were collected on growth characters, yields attributes and yield of rice. The result revealed that BRRI hybrid dhan3 produced the highest yield (8.47 t ha^{-1}) because of its higher panicle length (23.48 cm), grains $panicle^{-1}$ (100.33), weight of 1000 seeds (29.33g), straw yield (9.10 t ha^{-1}) and the lowest unfilled grains $panicle^{-1}$ (6.84). On the other hand, Zn application through soil application produced the highest grain yield (7.73 t ha^{-1}) and also produced the highest tillers $hill^{-1}$ (14.49), panicle length (23.69 cm), filled grains $panicle^{-1}$ (93.65) weight of 1000 seeds (27.03g), straw yield (8.00 t ha^{-1}) along with the lowest unfilled grains $panicle^{-1}$ (7.32). Interaction of BRRI hybrid dhan3 × Zn application through soil application was found promising for producing the highest yield, yield attributes and growth characters of rice.

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@	At the rate of
AEZ	Agro- Ecological Zone
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BRRI	Bangladesh Rice Research Institute
cm	Centi-meter
CV	Coefficient of Variance
cv.	Cultivar (s)
DAT	Days After Transplanting
^{0}C	Degree Celsius
et al.	And others
FAO	Food and Agriculture Organization
g	Gram (s)
HI	Harvest Index
i. e.,	That is
IRRI	International Rice Research Institute
Kg	Kilogram (s)
LSD	Least Significant Difference
m	Meter
m^{-2}	Meter squares
mm	Millimeter
MoP	Muriate of Potash
N	Nitrogen
No.	Number
NS	Not significant
pH	potential of hydrogen ion concentration
%	Percentage
RH	Relative humidity
S	Sulphur
SAU	Sher-e- Bangla Agricultural University
t ha^{-1}	Ton per hectare
TSP	Triple Super Phosphate
var.	Variety
viz.	Namely
Wt.	Weight
Zn	Zinc
$ZnSO_4.H_2O$	Zinc Sulfate Monohydrate

CHAPTER 1

INTRODUCTION

Rice is the most important food crop and a major food grain for more than a third of the world's population (Zhao *et al*., 2011). It is not only the main source of carbohydrate but also provides 69.61% of calories and 56.15% of the proteins in the average daily diet of the people (FAO, 2011). Rice alone constitute 97% of the food grain production in Bangladesh (BBS, 2012). It dominates over all other crops and covers 75% of the total cropped area (Rekabdar, 2004). Among three rice seasons, boro rice covers about 48.97% of total rice area and contributes to 38.14% of total rice production in the country (BBS, 2012). Rice-rice cropping system is the most important cropping system in Bangladesh. Long-term intensive cropping on the same piece of land with high yielding varieties often exhausts the availability of soil micronutrients. The continuous depleted soil fertility and poor management of plant micronutrients have appeared as major constraints has become hurdle in the effort to increase rice production in Bangladesh.

Nutrient stresses in Bangladesh soils are increasing day by day. Before 1980's, deficiency of NPK was a major problem in Bangladesh soils, and thereafter, along with NPK, deficiency of S and Zn are frequently reported (Islam *et al*., 1986; Hoque and Jahiruddin, 1994). Judicious and proper use of fertilizers can markedly increase the yield and improve the quality of rice (Alam *et al*., 2015). So, the appropriate fertilizer input that is not only for getting high grain yield but also for attaining maximum fertility (Khuang *et al*, 2008). Cereals, being exhaustive in nature, remove enough quantity of secondary and micronutrients and continuous cultivation of cereal-cereal systems which were highly nutrient responsive caused widespread deficiency of secondary and micronutrients. Till- date, the focus was on balanced application of N, P and K. But of late, it has been realized that deficiency of many secondary and micronutrients can also further limit the productivity of the many field crops (Gill and Singh, 2009). Zinc deficiency in rice has been widely reported in many rice-growing regions of the world. Low bioavailability of Zn in soil generally results in Zn deficiency in rice plants, and thus becomes one of the common constraints for Zn bio-fortification in rice grain. Zn deficiency in rice can be alleviated through Zn fertilization, which is considered to be a cost-effective method to alleviate Zn malnutrition (Zhao and Mcgrath 2009). Zn contents of cereal-based foods are quite inadequate to meet human demands. The problem is especially acute for rice consumers as rice (*Oryza sativa* L.) has the lowest Zn content among the cereals (Juliano, 1993). The main causes of Zn deficiency in crops are mainly soil-related: low Zn availability (high pH, calcareous and sodic soils), low total soil Zn content (especially in sandy, sodic, and calcareous soils), loss of soil organic matter, presence of nitrogen, sodium, calcium, magnesium and phosphates, restricted root exploration due to soil compaction or high water table and climate factors (Alloway, 2008). Zinc deficiency in crop plants results in not only yield reduction but also Zn malnutrition in humans, where a high proportion of rice is consumed as a staple food. The recent analyses made under the Copenhagen Consensus in 2008 (www.copenhagenconsensus.com) identified Zn deficiency, together with vitamin A deficiency, as the top priority global issue, and concluded that elimination of the Zn deficiency problem will result in immediate high impacts and high returns for humanity in the developing world.

Recently, water crisis in Bangladesh, has resulted in a move towards water- saving cultivation, from flooded to alternate wetting and drying to aerobic rice systems. Importantly, adoption of these water saving systems may decrease Zn availability (Farooq *et al*, 2016). High-yielding varieties and greater fertilizer inputs in Bangladesh were the strategies to raise the crop yield potential and feed increasing population. Zinc deficiency is considered as a major threat to the global and regional food security. Tolerance to environmental stress conditions has a high requirement for Zn to regulate and maintain the expression of genes needed to protect cells from the detrimental effects of stress (Cakmak, 2008).

As our soils are deficit in NPK with S and Zn, necessary study should be done to grow rice successfully and profitably. On the other hand, continuous application of large amounts of micronutrients can be toxic to the plants. If plant nutrients are not supplied in an adequate amount with an appropriate proportion, high yielding crop varieties under intensive cropping may fail to express their full potential. Zinc deficiency in plant is noticed when the supply of zinc to the plant is inadequate. Among the many factors which influence zinc supply to the plants, pH, concentration of zinc, iron, manganese and phosphorus in soil solution are very important. Fageria (2004) stated that decrease in availability of zinc in submerged soils are due to the formation of insoluble franklinite (ZnFe2O4) compound (submerged soil), insoluble ZnS (intense reduced condition), insoluble ZnCO3 (partial pressure of CO2 coupled with decomposition of OM) and insoluble Zn (OH)2 (alkaline pH). Widespread Zn deficiency has been found responsible for yield reduction in rice. Globally, more than 30 % of soils are low in plant-available Zn. Nonetheless, frequency of Zn deficiency is greater in rice than other crops, with more than 50 % of the crop worldwide prone to this nutritional disorder. For better zinc nutrition of human beings, cereal grains should contain around 40-60 mg Zn kg^{-1}, but in the present situation, the polished rice grain contains an average of only 12 mg Zn kg^{-1}. Zn is essential for gene regulation and expression under stress conditions and is therefore, required for protection against infections and diseases. Zn plays an important role in the production of proteins in the body and thus, helps in wound healing, blood formation and growth and maintenance of all tissues. Zn also supports immune function and storage release and function of insulin and it is important in host defense against cancer (Rajendra Prasad, 2010).

So, it is needed to apply Zn in soil for improving for plant uptake. Zn can be applied from different sources and in different methods. There are several methods to avoid zinc deficiency such as zinc supplementation, food fortification, soil application, ferti-fortification and conventional breeding etc. (Zhang *et al*., 2012). Zn can be applied to soil, seed and leaves and by dipping seedlings into a fertilizer solution. Selection of appropriate Zn sources for soil application is considered to be an alternative strategy to improve plant availability of Zn under lowland conditions. Generally, ZnSO4 is the most widely applied Zn source for its high solubility and low cost. There is increasing evidence showing that soil, root soaking, foliar or combined soil and foliar application of Zn fertilizers under field conditions are highly effective and very practical way to maximize uptake and accumulation of Zn in whole rice.

Application of Zn containing fertilizers to enhance the Zn content in the rice grain seems to be the possible solution for this problem. Hence, this study was aimed to investigate the effects of different methods of Zn applied through soil, root soaking and foliar on rice under field conditions.

With this background the present experiment was taken up with the following objectives.

(i) To observe the response of boro rice varieties to Zn for higher yield,

(ii) To study the suitable method of Zinc application on the growth and yield of rice, and

(iii) To find out the interaction of variety and method of Zn application on the growth and yield of rice.

CHAPTER 2

REVIEW OF LITERATURE

The literature pertaining to the present study of "**Influence of methods of zinc application on growth and yield of boro rice**" in popular rice varieties has been reviewed in this chapter under different heads.

2.1 Zinc status in Bangladeshi soils

In Bangladesh about 2 million hectares of land suffer from predominantly Zn deficiency in different agro ecological regions and 93 percent have some level of zinc deficiency in which one third of the soils are highly zinc deficient (SRDI, 2012).

Bhuiyan *et al.* (1993) revealed that the productivity of rice and wheat alone is still low (around 2 t ha^{-1}) because of many constraints along with poor soil and micronutrient deficiencies in soils. Multiple micronutrient deficiencies (Zn, Mn, Cu, B, Mo) occur in soils of the Indo-Gangetic plains (IGP) and are becoming more frequent as cropping intensity increases. Low soil organic matter levels, little retention of crop residues and limited return of animal manures to soils intensify these deficiencies (Mondal *et al.*, 1992).

Ahmed and Elias (1986) reported that increase of cropping intensity coupled with minimum use of fertilizer inputs are causing serious depletion both macro and micronutrients from soils. Thus, the micronutrients deficiencies (Zn, Mn, Cu, B, Mo) are becoming more in the region. Fifty four soil samples from ten districts of Bangladesh were studied for vertical distribution of DTPA extractable Zn, Cu, Fe and Mn and their relationship with some soil properties. As per critical limit prescribed for Zn and Fe, 44 and 20 percent of the soils could be rated as deficient in available zinc and iron respectively (Imamul *et al*. 2000).

Jahiruddin *et al*. (1992) reported that crop response to Zn and B appears to be progressively prominent. Zinc deficiency is the most widely recognized deficiency in rice field in Bangladesh, but it is difficult to identify in rice because it exists without specific symptoms. Where widespread zinc deficiencies have been identified in Bangladesh, such deficiencies were revealed to be more in the rice growing areas of the country (Deb, 1986).

Kalyanasundram and Mehta (2010) reported that there is possibility of an antagonistic relationship between zinc and phosphorus in soil and its contribution to phosphorus induced zinc deficiency.

In some places in Bangladesh, rice crop loss due to zinc deficiency ranged from 10 to 80 % and about 1.21 million hectares of wetland rice soils are assumed to be zinc deficient (Kabir, 1984). Islam (1992) reported that Zn deficiency is found in different regions of the country.

2.2 Role of Zinc in plants

Zinc is essential in protein synthesis and gene expression in plants (Cakmak, 2008). It has been estimated that about 10% of the proteins in biological systems need Zn for their structural and functional integrity. This element has also been indicated to be required as a co-factor in over 300 enzymes. During germination, production of reactive oxygen species (ROS) is well known and Zn plays a central role in detoxification of ROS in plant cells.

Zinc is one of the important micronutrient which is essential for plant growth. Plant roots absorb zinc as ion (Zn^{+2}). Zinc is closely involved in the diversity of enzymatic and N metabolism of plant. Zinc application to zinc deficient plant has been found to boost the growth of plants and yield of crop to a great extent. Zinc is the essential mineral element for protein synthesis (Dixit *et al*., 2012).

In rice, low plant-available Zn in soil causes leaf bronzing and poor tillering at the early growth stages, leading to delayed maturity and significant yield loss (Neue *et al*., 1998)

The Zn plays very important role in plant metabolism by influencing the activities of hydrogenase and carbonic anhydrase, stabilization of ribosomal fractions and synthesis of cytochrome. Plant enzymes activated by Zn are involved in carbohydrate metabolism, maintenance of the integrity of cellular membranes, protein synthesis, and regulation of auxin synthesis and pollen formation (Marschner *et al*., 1995).

Zn deficiency results in the development of abnormalities in plants which become visible as deficiency symptoms such as stunted growth, chlorosis and smaller leaves, spikelet sterility. Micronutrient Zn deficiency can also adversely affect the quality of harvested products; plants susceptibility to injury by high light or temperature intensity and to infection by fungal diseases can also increase. Zinc seems to affect the capacity for water uptake and transport in plants and also reduce the adverse effects of short periods of heat and salt stress (Imtiaz, 1995)

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Kumar *et al*. (2016) conducted an experiment on *Phaseolus vulgaris*.L, a micronutrient sensitive crop, which was grown in seven combinations of macro and micronutrients .The results suggested that on acidic soils, micronutrients application is indispensable for improving growth and yield of crops, particularly pulses, which are more sensitive to micronutrients. Its supplement can also increase the plant's use efficiency of macronutrients (NPK) due to their improved recovery efficiency by plant.

2.3 Effect of zinc application on rice:

2.3.1 Crop growth parameters

Khan *et al*. (2007) reported that, increasing the levels of Zn in soil significantly influenced growth in rice crop. The treatment receiving 10 kg Zn ha^{-1} significantly increased the plant height (74.38 cm) and maximum number of (17.41) tillers $plant^{-1}$. The minimum plant height (59.50 cm) was recorded in control. The increase in growth parameters might be assigned to adequate supply of zinc that might have increased the availability and uptake of other essential nutrients and there by resulting in the improvement of crop growth in rice.

Rao (2003) reported that application of 30 kg $ZnSO_4$ ha^{-1} significantly increased the plant height on sandy clay loam soils of Varanasi. While, Chaudary *and Sinha* (2007) found that application of $ZnSO_4$ @ 50 kg ha^{-1} significantly increased the plant height on silty - clay soil of Pusa, Bihar.

Ghoneim (2016) was observed that methods of Zn application significantly affected the plant height. Maximum plant height of 100 cm was recorded from the treatment with 15 kg Zn ha^{-1} as soil application which differs significantly from the other treatments. Minimum plant height was recorded with T_1 (control). The application of different methods of Zn application significantly increased the tiller number over control. The increased of tiller number by soil application of Zn may be attributed due to increase of nutrients availability in soil compared with other treatments.

Chaudhary *and Sinha* (2007) and Sriramachandrasekharan and mathar (2012) reported that the highest (28.25 g hill^{-1}) and the lowest (7.28g hill^{-1}) dry matter was accumulated in case of Zn4 (6kg) and Zn1 (0kg treatment at maturity and tillering respectively.

Several researchers observed that soil application of zinc sulphate significantly enhanced dry matter production over no zinc application (Mehdi *et al*., 1990; Agarwal and Gupta, 1994; Mali and Shaik, 1994; Pulla and Shukla, 1996 and Channal and Kandaswamy, 1997). On the other hand, Raju *et al.* (1994) did not observe any significant increase in dry matter production with soil application of zinc sulphate @ 20 kg ha^{-1} on clay loam soil with available DTPA- extractable zinc status of 1.8 ppm in Rabi season at Maruteru of Andhra Pradesh. Muthukumararaja *and* Sriramachandrasekharan (2012) reported that maximum dry matter production of (2.98 g pot^{-1}) at tillering and (40.93 g pot-1) at panicle initiation was obtained with application of 5 mg Zn kg^{-1} which was about 44 to 60% greater as compared with the treatment that did not receive zinc.

Boonchuay *et al*. (2013) observed that foliar application with 0.5% zinc sulfate spray at panicle initiation , booting and 1 week and 2 weeks after flowering showed significantly higher plant height (68.2cm), tillers plant^{-1} (17), plant dry matter (50.1 g plant^{-1}). The lowest was recorded in control where there was no foliar application (60.1cm), tillers plant^{-1} (10), plant dry matter (41.1 g plant^{-1}).

Hossain *et al.* (2001) reported that the application of Zn in combination with B and Mo significantly produced the highest plant height (123cm), panicle length (24.4cm,). The lowest was observed in control which did not receive zinc application.

Kabeya and Shanker (2013) studied that the treatment receiving 30kg $ZnSO_4$ ha^{-1} recorded the highest plant height (125cm), SPAD value (57) in rice. The highest straw dry matter (41g) and leaf dry matter (28g) was also obtained from this treatment, the lowest was obtained in control. Significantly increased plant height was observed with the application of $ZnSO_4$ @ 15 kg ha^{-1} on silty clay loam soil of Maharashtra (Chaphale and Badole, 1999).

Malik *et al*. (2011) observed that the treatment receiving 300ppm Zn in rice recorded the highest length of shoot+root (117cm), spikelet (10.67cm), dry matter production of root (3.9gm pot^{-1}), shoot (14.2g pot^{-1}) and the lowest height was observed at control. Application of $ZnSO_4$ @ 75 kg ha^{-1} significantly increased the dry matter production (63.60 q ha^{-1}) on clay loam soils of Khandwa, M.P. (Tomar *et al*., 1994).

Jena (1999) from a field experiment on clay loam soils of Bapatla reported that soil application of $ZnSO_4$ @ 50 kg ha^{-1} and seedling root dip in 2% ZnO significantly increased the dry matter production.

Kulandaivel *et al*. (2004) reported that application of 30 kg $ZnSO_4$ along with 5 kg $FeSO_4$ ha^{-1} produced higher dry matter on sandy clay loam soils of New Delhi.

Singh and Sharma (1994) noticed that basal dressing of all zinc carriers gave significantly higher tillers m^{-2} than foliar spray on silty clay soils of U.P. Whereas, Mustafa *et al.* (2011) conducted a field experiment at Faisalabad, Pakistan on Super basmati rice variety and noticed that basal application of 25 kg ha^{-1} of $ZnSO_4$ recorded more number of tillers m^{-2} (258) and it was at par with foliar application of 0.5% $ZnSO_4$ (254) at 15 DAT.

Khan et *al.* (2003) reported that the maximum plant height (101 cm) was recorded from the treatment @ 10 kg Zn ha^{-1} by soil Zn application which did not differ significantly from that of foliar spray of 0.2% $ZnSO_4$ on alkaline calcareous soils of Pakistan.

Sreenivasa Rao (2003) reported that on sandy clay loam soils of Bapatla, root dip plus foliar application of 0.5% $ZnSO_4$ significantly increased the plant height of rice.

Khanda *et al*. (1997) observed that foliar application of $ZnSO_4$ resulted in increased the dry matter production (9.05 t ha^{-1}) over no zinc application but it was on at par with soil application on sandy loam soils of Bhubaneswar.

The maximum number of tillers m^{-2} (415.67) was recorded where zinc was applied @ 10 kg ha^{-1} by soil dressing which did not differ significantly from that of foliar spray of 0.20% $ZnSO_4$ and root dipping of 1.0% $ZnSO_4$ on silt loam soils at Pakistan as observed by Khan *et al.* (2003).

Apoorva (2016) studied that the treatment receiving soil application of bio Zn @30 kg ha^{-1} recorded the plant height (100.6cm), the highest number of tillers m^{-1} (440.0) followed by foliar application of 0.2 % Zn as $ZnSO_4$ over control treatment.

A field investigation was carried out by Rahman *et al*. (2008) at Bangladesh Agricultural University, Mymensingh farm during 2004 Boro rice with seven treatments viz. T_1: S_0Zn_0 (control), T_2: $S_{10}Zn_0$, T_3: $S_{20}Zn_0$, T_4: $S_0Zn_{1.5}$, T_5: S_0Zn_3, T_6: $S_{10}Zn_{1.5}$, T_7: $S_{20}Zn_3$. The experimental result indicate that, the height of Boro rice plant and plant tiller was significantly affected due to application S and Zn. Apparently, the tallest plant (96.58 cm) and the maximum tiller (12.1) was observed in $S_{20}Zn_3$, the recommended dose of S and Zn (BARC, 1997), which was superior to all other treatments. The shortest plant (84.95cm) and the lowest tiller (7.6) was recorded in S_0Zn_0 (control).

2.3.2 Yield and Yield contributing parameters

Naik *and Das* (2007) reported that the soil application of Zn @ 1.0 kg ha^{-1} as Zn-EDTA recorded highest grain yield of (5.42 t ha^{-1}), filled grain percentage (90.2%), 1000-grain weight (25.41 g), number of panicles m^{-2} (452) and grain yield 5.42 t ha^{-1} compared to basal application of $ZnSO_4.7H_2O$.

Ghoneim (2016) reported that the highest number of panicles m^{-2} was recorded in soil application of Zn followed by foliar application of Zn, while the minimum number of panicles m^{-2} rice plant was recorded in control. The number of spikelet's $panicle^{-1}$, percentage of filled grain and 1000-grain weight followed the same trend of response i.e. increased with different methods of Zn application compared to control but, no significant differences were found amongst the various methods. The highest grain yield of 9.60 tones ha^{-1} was recorded by soil application of Zn. No significant differences were observed in grain yield with root soaking or foliar. It is also observed that straw yield of rice significantly increased with different methods of Zn application (soil, root soaking or foliar application of Zn) compared with no zinc application, but, no significant difference were observed between Zn application methods.

Prasad *et al.* (2010) reported that the highest grain yield (4.35 t ha^{-1}) and straw yield of 7.27 t ha^{-1}) was recorded under 100% crop residue level and 10 kg Zn ha^{-1} in rice compared no zinc application treatment. Perusal of data revealed that minimum rice yield (7.09 t ha^{-1}) was recorded with absolute control plots where no application of zinc and sulphur was done during entire experimentation period. Whereas corresponding maximum (7.63 t ha^{-1}) rice yield was recorded with combined application of 30 kg sulphur and 6 kg zinc (Ali *et al.*, 2012; Singh *et al.*, 2002). This combined analysis suggests that for better output and for balanced nutrition combined application is advocated.

Mustafa *et al*. (2011) observed that Zn application had significantly pronounced effect on growth and yield of rice. Maximum productive tillers m^{-2} (249.80) and maximum grain yield (5.21 t ha^{-1}) were noted with basal application at the rate 25 kg ha^{-1}, 21 % $ZnSO_4$ and minimum productive tillers (220.28) and minimum grain yield (4.17 t ha^{-1}) was noted in foliar application at 75 DAT @ 0.5% Zn solution.

Ram *et al.* (2005) reported that maximum number of filled grains $panicle^{-1}$ was observed with basal application of 20 kg $ZnSO_4$ ha^{-1} along with foliar spray of 0.5% $ZnSO_4$ three times, initiated from 20 DAT at 10 days interval on silty loam soils of Faizabad (U.P.).

Hossain *et al*. (2001) reported that the application of Zn in combination with B and Mo significantly produced higher grain yield (4.7 t ha^{-1}), straw yield (7.07 t ha^{-1}) and 1000-grain weight (23.5g) in rice and the minimum recorded in control where no micronutrients were applied.

Singh *et al*. (2012) observed that the maximum plant height (101.7cm), dry matter (28.25 g $hill^{-1}$) and grain yield (7.5 t ha^{-1}) ware recorded with application of Zn@ 6kg and minimum plant height (78.5cm), dry matter (7.8 g $hill^{-1}$) and grain yield (6.0 t ha^{-1}) ware seen in control.

Boonchuay *et al*. (2013) observed that foliar application with 0.5%zinc sulfate spray at panicle initiation ,booting and 1 week and 2 weeks after flowering showed significantly higher grain weight (20.1g $plant^{-1}$), straw weight (30.1g $plant^{-1}$), panicles $plant^{-1}$ (13) and the lowest was seen in control where there was no foliar application.

Mustafa *et al*. (2011) conducted a field experiment at Faisalabad, Pakistan on Super basmati rice variety and reported that basal application of 25 kg $ZnSO_4$ ha^{-1} of recorded more test weight and it remained at par with foliar application of 0.5% $ZnSO_4$ and root dip treatments with zinc solution.

Trivedi *et al.* (1998) concluded that on clay soils of Gujarat, application of 11.2 kg $ZnSO_4$ ha^{-1} produced higher straw yield with the cultivar, Jaya than GR-11 during kharif season.

A field investigation was carried out by Rahman *et al*. (2008) at Bangladesh Agricultural University, Mymensingh farm during 2004 with Boro rice having seven treatments viz. T1: S_0Zn_0 (control), T2: $S_{10}Zn_0$, T3: $S_{20}Zn_0$, T4: $S_0Zn_{1.5}$, T5: S_0Zn_3, T6: $S_{10}Zn_{1.5}$, T7: $S_{20}Zn_3$. The experimental result indicated that, panicle length was significantly affected to S and Zn application. The highest Panicle length (25.26 cm) was obtained from $S_{20}Zn_3$ and the lowest (22.73 cm) is recorded in in S_0Zn_0 (control). The number of effective tillers $hill^{-1}$ due to different treatments varied from 7.6 to 12.1. The weight of 1000 grains was not significant with various treatments. The 1000-grain weight followed the order T4>T2>T7>T5>T3>T6>T1. The highest grain yield (5.76 t ha^{-1}) was observed in $S_{20}Zn_3$. The $S_{10}Zn_{1.5}$ which is the 50% of recommended dose produced the intermediate grain yield (4.95 t ha^{-1}). The lowest grain yield (4.35 t ha^{-1}) was obtained in control. A significant and positive effects of S and Zn on straw yield of Boro rice was observed. The highest straw yield (7.32 t ha^{-1}) obtained in $S_{20}Zn_{1.5}$, the second highest in $S_{20}Zn_0$ (7.25 t ha^{-1}) and the lowest (5.47 t ha^{-1}) in S_0Zn_0.

Abid *et al*. (2011) reported that the growth and rice yield were significantly enhanced by application of Zn, Fe and Mn either alone or in various combinations. The treatment comprising 10 mg each of Mn and Zn added per kg soil along with basal dose of NPK fertilizers proved to be the best combination. It is evident that the highest number of grains $panicle^{-1}$ (118.66), 1000 grain weight (23.93g) and maximum paddy yield (78.73 g) was recorded by treatment (NPK+Mn+Zn) and minimum yield (20.53 g) was recorded in (control). It was probably due to the more balanced nutrient ratio, which improved the yield and yield contributing characteristics of rice

Shivay *et al*. (2015) observed that application of 5 kg Zn ha^{-1} (soil) + 1 kg Zn ha-1 (foliar) recorded the highest grain yield (4.52 t ha^{-1}), straw yield (8.12 t ha^{-1}), tillers m^{-2} (342), grains $panicle^{-1}$ (94), 1,000 grain weight (22.7g) which was significantly more than soil application of ZnS or Zn-coated urea (ZnCu), which in turn was significantly superior to foliar application of ZnS.

Sharma *et al*. (1999) reported that soil application of 36 kg $ZnSO_4$ ha^{-1} produced significantly higher effective tillers m^{-2} on clay loam soils of Rajasthan.

It was observed that the highest mean values of yield and its components i.e. panicle weight (2.38g), number of filled grains $panicle^{-1}$ (112.73), number of panicles m^{-2} (482.2), 1000 grain weight (22.15g), grain yield (3.80 tons ha^{-1}), straw yield (5.05 tons ha^{-1}), were recorded by treatment (soil + foliar) of Zn in combination with 50 % Mineral N+ 50 % organic N (Gomaa *et al*., 2015).

Khan *et al*. (2007) reported that, increasing the levels of Zn in soil significantly influenced yield and yield components of the rice crop. The treatment receiving 10 kg Zn ha^{-1} significantly increased maximum number of panicles $plant^{-1}$(15.88) and spikelet's $panicle^{-1}$(86.48). The highest grain yield of (101.80 g pot^{-1}) and straw yield (140.40 g pot^{-1}) was recorded in treatment receiving 10kg Zn ha^{-1} which was statistically at par with the treatment receiving 15 kg Zn ha^{-1}. The minimum grain yield (73.90 g pot^{-1}), straw yield (102.28 g pot^{-1}) was recorded in control. The increase in yield parameters might be ascribed to adequate supply of zinc that might have increased the availability and uptake of other essential nutrients and there by resulting in the improvement of crop growth in rice.

Lowland rice responded significantly to applications of Zn, Cu, B, Mo, Mn and Fe .The adequate rates of micronutrients for maximum grain yield were Zn 33 mg kg^{-1}, Cu 25 mg kg^{-1}, B 26 mg kg^{-1}, Mo 10 mg kg^{-1}, Mn 250 mg kg^{-1}, and Fe 1269 mg kg^{-1}. In addition to grain yield, straw yield, panicle density, and root growth of lowland rice were also improved with the addition of most of these micronutrients (Fageria, 2004).

Sinha (2007) noticed that combined application of 120 kg N together with 25 kg $ZnSO_4$ ha^{-1} resulted in significantly higher effective tillers m^{-2} on silty-clay soil of Pusa, Bihar.

Kumar *et al*. (2016) found that application of 20 kg $ZnSO_4$ ha^{-1} incubated or blended either with press mud or FYM produced significantly higher number of filled grains panicle^{-1}, but, it was at par with the application of 40 kg $ZnSO_4$ ha^{-1} alone on sodic soils of U.P.

Mustafa *et al*. (2011) conducted a field experiment at Faisalabad, Pakistan on Super basmati rice variety and reported that basal application of 25 kg $ZnSO_4$ ha^{-1} recorded more test weight and it remained at par with foliar application of 0.5% $ZnSO_4$ and root dip treatments with zinc solution.

Jena (1999) noticed significant increase in grain yield with the soil application of 50 kg $ZnSO_4$ ha^{-1} on clay loam soils of Bapatla. Similarly, increased grain yield was recorded with application of $ZnSO_4$ @ 20 kg ha^{-1} in coastal area of Bhubaneswar (Katyal and Gangwar, 2000). While, Channabasavanna *et al.* (2001) observed that on deep black soils of Siriguppa (Karnataka), application of $ZnSO_4$ @ 25 kg ha^{-1} significantly increased the grain yield. Similar result was also obtained with the application of 50 kg $ZnSO_4$ ha^{-1} in red loam soil of Bhavanisagar (Sankaran *et al.*, 2001).

Kulandaivel *et al*. (2003) noticed that application of 30 kg $ZnSO_4$ ha^{-1} along with 10 kg $FeSO_4$ ha^{-1} produced significantly higher straw yield on loamy soil of New Delhi.

Application of N along with Zn increased grain yield and grain-to-straw ratio significantly. Ammonium sulfate used as N source along with Zn gave significantly higher yield as 25% in grain and 14 % in straw and the highest grain-to-straw ration compared to all other treatments. It was possibly due to availability of more Zn and more number of filled grains under reduced pH. Application of zinc along with N had synergistic effect on N and Zn uptake in rice. (Rahman *et al*., 2002).

Kumar and Singh (2006) conducted a trial on a silty loam soil and reported that foliar application with 0.5% $ZnSO_4$ at three weeks after transplanting recorded higher number of productive tillers m^{-2} but it was on a par with soil application and root dip treatments.

Ravikiran and Reddy (2004) found that foliar spray of Zn increased number of productive tillers from control to 0.5 % Zn spray followed by soil application but the highest increase was noticed with 0.5% spray only.

An investigation wes conducted by Alam and Kumar (2015) at the Agricultural Farm in Newaji Tola in Saran district of Bihar, India to evaluate the effect of Zinc on growth and yield of rice var.

Pusa Basmati-1. The experiment was laid out in a randomized complete block design (RCBD) with four treatments (0 kg ha^{-1} ZnSO4, 5 kg ha^{-1} ZnSO4, 10 kg ha^{-1} ZnSO4 and 20 kg ha^{-1} ZnSO4) and four replications. The result revealed that the maximum panicle length (23.39cm), the maximum number of effective tillers m^{-2} (317) ware obtained from 10 kg ha^{-1} ZnSO4 and the minimum panicle length (16.57 cm), the minimum number of effective tillers m^{-2} (225) ware obtained from 0 kg ha^{-1} ZnSO4. The maximum 1000 grain weight (24.97 g) was obtained from 10 kg ha^{-1} ZnSO4 and the minimum 1000 grain weight (22.25 g) was obtained from 0 kg ha^{-1} ZnSO4. The maximum grain yield (32.45 q ha^{-1}) was obtained from 10 kg ha^{-1} ZnSO4 and the minimum grain yield (24.32 q ha^{-1}) was obtained from 0 kg ha^{-1} ZnSO4. The maximum straw yield (69.25 q ha^{-1}) was obtained from 10 kg ha^{-1} ZnSO4 and the minimum straw yield (46.37 q ha^{-1}) was obtained from 0 kg ha^{-1} ZnSO4. The plant height and grain yield of rice, significantly increased at 1% and 2 % zinc concentrations, compared with those of zero zinc (control). At the rate of 0.5 % zinc, also an increase was obtained but not significant. A positive correlation was found between zinc concentration and the rice growth and yield. Number of tillers and panicle length also non significantly increased by zinc application. The application of Zn at rates as high as 10 mg/kg soil increased the height and improved the yield-contributing characters and the shoot, straw, and grain yields in IR28; it has no effect in IR10198-66-2. In general, the shoot, straw, and grain yields were higher in IR10198-66-2 than in IR28 (Korayem *et al*. 1993).

Manas *et al*. (2017) reported that the zinc contents and uptake in rice plant at maturity, significantly was influenced by various levels of zinc application. The higher concentration of Zn in grain, husk and straw was showed at 7.5 kg Zn ha^{-1} followed by 5.0 kg Zn ha^{-1} application. The magnitude of Zn concentration was found in an order; straw (88.32-124.77 mg kg-1)>grain (23.20-34.27 mg kg^{-1}) >husk (20.37-30.80 mg kg^{-1}).

Ram *et al*. (1995) observed the maximum filled grains panicle were with the treatment that received combined application of 20 kg $ZnSO_4$ ha^{-1} as basal + three sprays of 0.5% $ZnSO_4$ solution, but it was at a par with separate application of $ZnSO_4$ as soil and foliar spray on partially reclaimed sodic soil at Faizabad, U.P.

There was no significant impact on 1000- grain weight of rice by zinc application methods (basal and foliar spray) on a partially reclaimed sodic soil at Faizabad as observed by Ram *et al*. (1995), Khan *et al*. (2003) and Reddy *et al*. (2011).

Sharma *et al*. (1999) observed the highest grain yield with soil application of 36 kg $ZnSO_4$ ha^{-1} which did not differ significantly with that of two sprayings of $ZnSO_4$ @ 0.5% twice at 30 and 45 DAT on clay loam soils of Rajasthan.

It was observed that the highest mean values of yield and its components, number of panicles m^{-2} (446.6), the number of filled grains panicle^{-1} (13.3), the highest grain yield (5355 kg ha^{-1}). The highest straw yield (6347kg ha^{-1}) were recorded by the treatment receiving RDF +Soil application of bio Zn @30 kg ha^{-1} which was at par with RDF +foliar application of 0.2 % Zn as ZnSO4 and RDF +foliar application of 1 ml Zn as nano zinc (Apoorva, 2016).

Dixit *et al*. (2012) observed that application of Zn at 25kg ha^{-1} in rice significantly increased the panicle length(24.96 cm), protein content (11.56%), grain yield (60.34 q ha^{-1}), straw yield (77.37 q ha^{-1}) with significant difference from than that of plant grown without Zinc treatment. Keram *et al*. (2012) recorded that the highest grain (3.88 t ha^{-1}) and straw (4.76 t ha^{-1}) yield as were observed in treatment consisting NPK+20 kg Zn ha^{-1} compared to NPK alone.

This study was conducted by Maqsood *et al*. (2008) at agronomic research area, University of Agriculture, Faisalabad, during kharif 2008 to evaluate the effect of different methods and timing of zinc application on growth and yield of rice. Experiment was comprised of eight treatments viz., control, rice nursery root dipping in 0.5 % Zn solution, ZnSO4 application at the rate of 25 kgha^{-1} as basal dose, foliar application of 0.5 % Zn solution at 15, 30, 45, 60 and 75 days after transplanting. Super Basmati, a promising variety of rice was used as a test crop. Remarkable effects were noted on yield components such as number of productive tillers hill $^{-1,}$ kernel panicle^{-1}, 1000-kernel weight, biological yield, and kernel yield and harvest index. Maximum productive tillers m^{-2} (249.80) were noted with basal application at the rate 25 kg ha^{-1} and minimum (220.28) were recorded with foliar application at 60 DAT @ 0.5 % Zn solution. Zinc application methods and timing had significantly pronounced effect on paddy yield. Maximum rice yield (5.21 t ha^{-1}) was achieved in treatment Zn (Basal application at the rate of 25 kg ha^{-1} and minimum paddy yield (4.17 t ha^{-1}) was noted in Zn_2 (foliar application at 75 DAT @ 0.5% Zn solution). Zinc application increases the crop growth rate of rice.

A field experiment was conducted by khan *et al*. (2003) where comparative effect of three different methods of zinc application was studied, aimed at alleviating Zn deficiency in transplanted flood rice (cv. Irri.6) grown in alkaline soil. Three methods were tried i.e. nursery root dipping in 1.0% $ZnSO_{4,}$0, 20% $ZnSO_4$ Solution spray after transplanting and 10 g Zn ha^{-1} by field broadcast method. The yield and yield parameters increased significantly by the application of Zn by any method. Among the the methods the effect of Zn was non-significant on yield components like tiller m^{-2}, spikelet's panicle^{-1}, % filled grains, 1000-grain weight and straw yield. However, soil application of Zn@10 kg ha^{-1} was rated superior because it produced significantly higher paddy yield.

2.4 Effect of application of zinc on the uptake of N, P, K and Zn in rice

Khan *et al.* (2007) observed that the highest concentration of Zn in soil was recorded by the cumulative application of 10 kg Zn ha^{-1} (1.18 mg kg^{-1}) in rice, the lower Zn concentrations (0.81mg kg^{-1}) was obtained from 5 kg Zn ha^{-1}, while the lowest concentration was obtained from check plot (0.30mg kg $^{-1}$).

Zn application of 25kg ha^{-1} as ZnSO4 recorded the highest uptake of N (111.87kg ha^{-1} in grain) (43.21kg ha^{-1} in straw), P (16.29 kg ha^{-1} in grain) (6.90kg ha^{-1} in straw), K (34.39kg ha^{-1} in grain) (100.50kg ha^{-1} in straw) and Zn (163.52 g ha^{-1} in grain) (131.42g ha^{-1} in straw) in rice (Dixit *et al* ., 2012) the lowest uptake was seen in control.

In rice soils P fertilization decreased Zn uptake by plant even in the case of Zn fertilization, which is due to Zn absorbance by iron oxides, and amorphous manganese under saturated conditions. Zn deficiency in the soil or its unavailability to plant significantly decreases crop yield as well as grain Zn concentration. If the soil is slightly deficient in P or Zn, adding one of the nutrients result in the deficiency of the other one, which can be compensated by fertilizing both nutrients (Barben *et al*., 2010).

Application of 100% crop residue along with Zn @ 10.0kgha^{-1} significantly enhanced the available N (370 kg ha^{-1}), P (44 kg ha $^{-1}$), K (176kg ha^{-1}), Zn (1.64 mg kg^{-1}) content of soil over control (Prasad *et al*., 2010).

Application of 5 kg Zn ha^{-1} (soil) + 1 kg Zn ha^{-1} (foliar) recorded the highest total uptake of Zn(1207.0g ha^{-1}), N (103.5 kg ha^{-1}), P (25.43 kg ha^{-1}), K (314.3 kg ha^{-1}) at harvest which was significantly higher than ZnCu, which in turn was superior to soil or foliar application of ZnS (Shivay *et al*., 2015)

Application of Zn significantly decreased P uptake by rice in straw and grain. The highest concentration of straw P (11.85%) and grain P (0.98%) was seen in control compared to all other treatments. The highest Zn uptake in grain (18.4mg kg^{-1}) and straw (64.5 mg kg^{-1}) was seen in the treatment receiving 8 mg zinc sulfate chelate. The lowest Zn content was related to the control treatment (13.34 mg kg^{-1}) (Hoseinzade *et al*., 2014).

Keram *et al.* (2012) observed highest uptake of N (123.19 kg ha^{-1}), K (90.96 kg ha^{-1}) and Zn (327.74 g ha^{-1}) with the application of 20 kg Zn ha^{-1} along with recommended dose of NPK compared to control. Whereas the highest total P uptake (19.27 kg ha^{-1}) was recorded in control and was declined with increasing levels of Zn. The increase in total N, K and Zn uptake could be attributed to synergistic effect between N and Zn and due to the positive interaction of K and Zn, respectively. Rai and Yadav (2011) studied the influence of inorganic and organic sources on enzyme activities in wheat. They found that the highest dehydrogenase activity was in 100% N through FYM (53 µg TPF produced g soil d^{-1}).

Srilatha *et al*. (2013) observed that soil enzyme activities increased with increasing rate of NPK application. Acid phosphatase ranged from 64.3 to 90.3, 77.3 to 127.9, 67.6 to 121.3 and 48.8 to 78.1 during aman and 72.7to 120.6, 169.8 to 206.1, 86.1 to 138.7 and 65.6 to 100.5 µg of p-nitrophenol released g^{-1} soil h^{-1} at 30, 60, 90 DAT and at harvest, respectively during boro. Alkaline phosphatase activity ranged from 73.5 to 94.8, 81.8 to 135.2, 70.2 to 125.9, 52.8 to 92.6 in aman and 81.7 to126.1, 127.9 to 177.4, 85.6 to 151.4 and 69.1to 109.4 µg of p-nitrophenol released g^{-1} soil h^{-1} at 30, 60, 90 DAT and at harvest, respectively in boro.

CHAPTER 3

MATERIALS AND METHODS

A field experiment entitled "**Influence of zinc application methods on growth and yield of boro rice"** was carried out under field conditions during boro season of 2017-18 at the Agronomy field of Sher-e-Bangla Agricultural University, Dhaka -1207. The details of the research work carried out, materials used and methodologies adopted in this research are described here under different heading.

3.1 Experimental site

The farm is geographically located at $23^0 77'$ N latitude and $90^0 35'$ E longitude at an altitude of 8.6 m above mean sea level under the Agro-ecological zone of Modhupur Tract, AEZ-28.

3.1.1 Weather during the crop growth period

The climate of the experimental site is subtropical. It receives rainfall mainly from South West monsoon (May-October) and winter season from November to February. The weather data during experimental period was collected from the Meteorological Station of Bangladesh, Sher-e Bangla Nagar, presented in Appendix II.

The maximum temperature during the crop growth period ranged from 15^0C to 35^0 C with an average of 28.5^0 C during 2018, while the minimum temperature ranges wes from 10^0 C to 24^0 C with an average 17.33^0 C. The mean relative humidity ranged from 57 percent to 74 percent. The total rainfall received during the crop growth period was 302 mm received in 27 rainy days.

3.1.2 Soil

The soil of the research field is slightly acidic in reaction with low organic matter content. The experimental area was above flood level and sufficient sunshine having available irrigation and drainage system during the experimental period. Soil sample from 0-15 cm depth were collected from experimental field and the soil analysis were done from Soil Resources Development Institute (SRDI), Dhaka. The experimental plot was high land having pH 5.6. The physical properties and nutritional status of soil of the experimental plot are given in Appendix III.

3.2 Plant materials and features

BRRI dhan45, BRRI dhan63 and BRRI hybrid dhan3 were used as planting materials for the study. These varieties are recommended for boro season. The features of these varieties are presented below:

3.2.1 BRRI dhan45: BRRI dhan45 variety is grown in boro season. This variety is recommended for cultivation in medium high land and medium low land. The life cycle of the variety is 140-145 days. It attains a plant height of 95-100 cm. It gives an average yield of 6-6.5 t ha^{-1}.

3.2.2 BRRI dhan63: BRRI dhan63 is a good variety to cultivate in boro season. Average plant height is 100-105 cm. Its life cycle is about 148-150 days. The average yield is 6.5-7 t ha^{-1}.

3.2.3 BRRI hybrid dhan3: BRRI hybrid dhan3 variety is grown in boro season. This variety is recommended for cultivation in medium high land and medium low land. The cultivar matures at 145 days after planting. It attains a plant height of 110 cm. Average yield of the variety is 9 t ha^{-1}.

3.3 Experimental details

3.3.1 Treatments:

Two sets of treatments included in the experiment were as follows:

Factor A: Variety - 3

i. V_1 = BRRI dhan45

ii. V_2 = BRRI dhan63

iii. V_3 = BRRI hybrid dhan3

Factor B: Methods of Zn application - 4

i. F_0 = Control (No zinc application)

ii. F_1= Root soaking

iii. F_2 = Foliar spray

iv. F_3 = Soil application

3.3.2 Experimental design

The experiment was laid out in a split-plot design with three replications having variety in the main plots and methods of zinc application in the sub-plot. There were 12 treatment combinations. The total numbers of unit plots were 36.

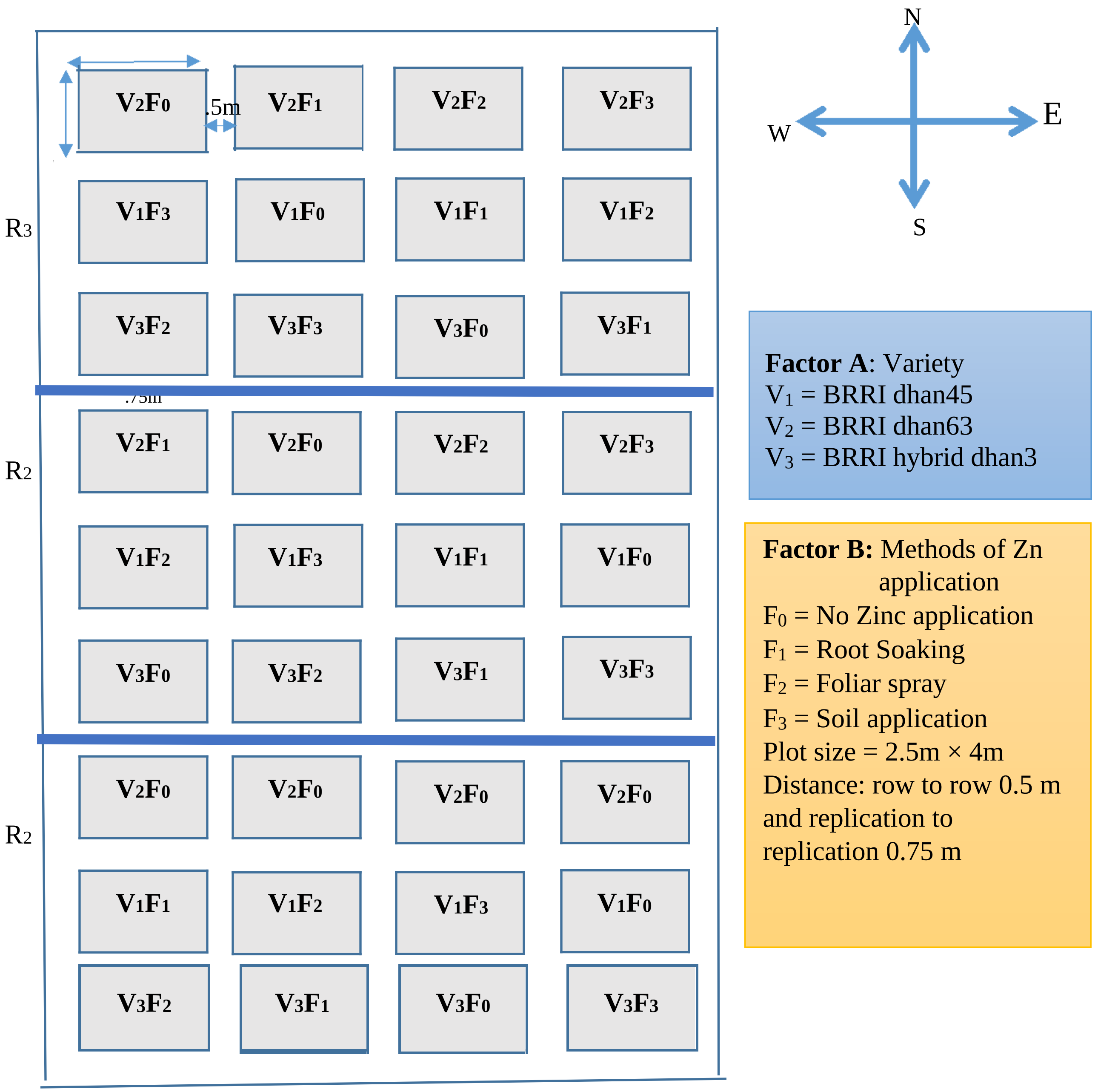


Figure 1. Layout of the experimental plot

Table 1. **Time and methods of Zn application**

Symbolic names	Methods of Zn application
F_0 (no Zn applied)	-
F_1 (Root soaking)	Root soaking in 1.50% $ZnSO_4H_2O$ solution prior transplanting
F_2 (Foliar spray)	Spray 2 % $ZnSO_4H_2O$ solution at 20 DAT
F_3 (Soil application)	Soil application ($ZnSO_4H_2O$) just before transplanting (15 kg ha^{-1})

3.4 Cultivation details

Details of cultivation practices are presented below.

3.4.1 Growing of crops

3.4.2 Raising seedlings

3.4.3 Seed collection

The seeds of the rice varieties i.e. BRRI dhan45, BRRI dhan63 and BRRI hybrid dhan3 were collected from Bangladesh Rice Research Institute (BRRI), Joydevpur, Gazipur.

3.4.4 Seed sprouting

Healthy seeds were selected by specific gravity method and then immersed in water bucket for 24 hours and then it was kept tightly in gunny bags. The seeds started sprouting after 48 hours and were sown in nursery bed after 72 hours.

3.4.5 Nursery

The field selected for nursery was thoroughly ploughed. Seed rate was calculated based on test weight and germination percentage. Sprouted seed ware sown uniformly in the nursery bed on 23-11-2017. All the three test varieties were sown in an area of 1 m^2each on the same day i.e. 23-11-2017. Later, the seed ware covered immediately and then a light irrigation was given.

The nursery of $3m^2$ was fertilized with a basal dose of 65g urea, 95g of single super phosphate and 25g of muriate of potash as recommended by the BRRI. Weeding and plant protection measures were taken up as and when necessary. Top dressing of urea @ 25g was given at 10 days after sowing.

3.4.6 Main field preparation

The experimental field was ploughed twice with a tractor drawn puddler to obtain the required puddle after impounding 5cm of standing water in the field. After thorough puddling, leveling was done accordingly. Water was drained out of the field in order to layout the plan of the experiment as shown in Figure 1.

3.4.7 Manures

A well decomposed cowdung @ 10 t ha^{-1} was applied at the time of final land preparation.

3.4. 8 Fertilizer application

A recommended dose of urea, TSP, MoP and gypsum @ 180, 165, 180, and 90 kg ha^{-1} respectively ware applied in the field for N, P_2O_5, K_2O and S. The whole amount of fertilizer were applied at the time of final land preparation except urea. One third urea was applied at final land preparation and rest amount was applied in two equal spilts at 30 and 60 DAT.

3.4.9 Transplanting

Rice seedlings of 40 days old were transplanted in experimental plots keeping two seedlings $hill^{-1}$ for inbred by maintaining a spacing of 25 cm × 15 cm and one seedling $hill^{-1}$ for hybrid at the spacing of 20 cm× 15 cm on 02-01-2018.

3.5 Intercultural operations

3.5.1 Gap filling

Some seedlings from the nursery were transplanted alongside of the irrigation channels at the time of transplanting for the purpose of gap filling. Gap filling was done at the tenth day by using seedlings planted alongside the channels which were also lifted along with the intact soil in order to maintain uniform population.

3.5.2 Irrigation

A thin film of water was maintained at the time of transplanting for better establishment of the seedlings. From the third day onwards, 2 to 3 cm depth of water was maintained up to the panicle initiation stage except at the time of top dressing of nitrogen, where the water was drained out and reflooded after 48 hours to maintain 5 cm depth of water up to physiological maturity. After dough stage, water was gradually drained out to facilitate easy harvesting of the crop.

3.5.3 Weeding

Weeds were removed from the plots by manual labour from four weeks after transplanting and the plots were kept weed free as and when necessary. Second weeding was taken up at Panicle Initiation (PI) stage (60 DAT).

3.5.4 Plant protection

No major incidence of pests and diseases was observed except minor incidence of leaf folder, observed at 35 days after planting, which was controlled by spraying curbofuran 3G @ 1.5 kg a.i. ha^{-1} of water.

3.5.5 Harvesting and Threshing

At maturity, ten hills from each plot except border rows were harvested and data on yield attributes were taken from sampled plant. For taking yield data, central $1m^2$ area was harvested and carried them the threshing floor. The plot wise crops were dried in the threshing floor for three days. Then threshing was done by manual labour and the grains was cleaned and sun dried for three days. Grain and straw yields were recorded plot wise after drying on threshing floor.

3.6 Sampling

3.6.1 Destructive sampling

For destructive sampling, three successive hills were sampled at each time from the second row next to the border row to record dry matter production. The destructive samples taken were dried in a shade and then oven dried at 72^0C for 72 hours till a constant weight was obtained. Sampling was done at 30, 60, 90 DAT and at harvest to study the dry matter production of rice.

3.6.2 Non-destructive Sampling

For non-destructive sampling, 5 representative hills were selected randomly and tagged in each plot second rows opposite from destructive sample from each side of the plot. Data on plant height and tillers hill^{-1} data were recorded at different growth stage of the crops from these five hills.

3.7 Data recording

The following data were collected during the study period:

A. Crop growth characters

i. Plant height (cm) at 30, 50, 70, 90 DAT and at harvest

ii. Number of tillers hill^{-1} at 30, 50, 70, 90 DAT and at harvest

iii. Dry weight of plant at 30, 60, 90 DAT and at harvest

B. Phenological characters and yield attributes

i. Number of effective tillers hill^{-1}

ii. Number of non-effective tillers hill^{-1}

iii. Length of panicle (cm)

iv. Number of filled grains panicle^{-1}

v. Number of unfilled grains panicle^{-1}

vii. Weight of 1000 grains (g)

C. Yield and harvest index

viii. Grain yield (t ha^{-1})

ix. Straw yield (t ha^{-1})

x. Biological yield (t ha^{-1})

xi. Harvest index (%)

3.7.1 Pre-harvest data observation

3.7.1.1 Plant height (cm)

Plant height was recorded from five randomly tagged hills in each treatment in all the three replications. Plant height was measured from the base of the plant to tip of the top most leaf o every labeled hill at each sampling at 30,50,70,90 days after transplanting and at harvest. The plant height was expressed in centimeters (cm).

3.7.1.2 Number of tillers hill^{-1}.

Total number of tillers hill^{-1} from five labeled plants at 30, 50, 70, 90 DAT and at harvest ware counted and expressed as total number of tillers hill^{-1}.

3.7.1.3 Number of effective tillers hill^{-1}.

Number of ear bearing tillers from five labeled plants at harvest were counted and expressed as effective tillers hill^{-1}.

3.7.1.4 Number of non-effective tillers hill^{-1}

Number of without ear bearing tillers from five labeled plants at harvest were counted and expressed as non-effective tillers hill^{-1}.

3.7.1.5 Dry matter accumulation

Three successive hills were sampled, as mentioned earlier, at 30, 60, 90 DAT and at harvest. The samples were dried in shade first and then dried in hot-air oven at 72^0C for 72 hours till to attain constant weight. Sample dry weights were summed up to arrive at mean dry matter hill^{-1} in individual treatment. The mean dry weight was expressed in g hill^{-1}.

3.7.2 Post–harvest observation

3.7.2.1 Panicle length (cm)

Measurement of panicle length was taken from basal node of the rachis to apex of each panicle. Each observation was an average total panicles of ten hill.

3.7.2.2 Filled grains panicle^{-1} (no.)

A grain was considered filled when a kernel was present there in. So, the number of total filled grains present total panicles of ten hill were recorded and finally averaged.

3.7.2.3 Unfilled grains panicle^{-1} (no.)

Unfilled grains means the absence of any kernel inside the floret and such grains of the total panicles of ten hill were counted and finally averaged.

3.7.2.4 1000 seed weight (g)

One thousand grains were counted from a random sample for each treatment from a composite sample drawn from the net plot yield, weighed and expressed as 1000 seed weight (g).

3.7.2.5 Grains yield (t ha^{-1})

The crop harvested from $1m^2$ area from each plot was bundled separately and sun dried and later threshed individually plot-wise by manual labour. Cleaning of the grain was done after threshing followed by sun drying for three days to record the final yield. Expressing the final grain yield in t ha^{-1}.

3.7.2.6 Straw yield (t ha^{-1})

Straw from $1m^2$ are of each plot was dried in sun for three days. Straw yield finally expressed as t ha^{-1}.

3.7.2.7 Biological yield (t ha^{-1})

Grain yield and straw yield were all together regarded as biological yield. Biological yield was calculated with the following formula:

Biological yield (t ha^{-1}) = Grain yield (t ha^{-1}) + Straw yield (t ha^{-1})

3.7.2.8 Harvest index (%)

Harvest index is the ratio of grain yield to the total biological yield (grain + straw) and expressed in percent. It was calculated using the following formula given here under by Yoshida (1981).

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (t ha}^{-1}\text{)}}{\text{Biological yield (t ha}^{-1}\text{)}} \times 100$$

3.8 Statistical analysis

All the data recorded are subjected to statistical analysis using computer software program statistix 10. Standard error at 0.05 level were worked out for the effects, which were significant. The results were presented in tables and depicted graphically wherever necessary.

CHAPTER 4

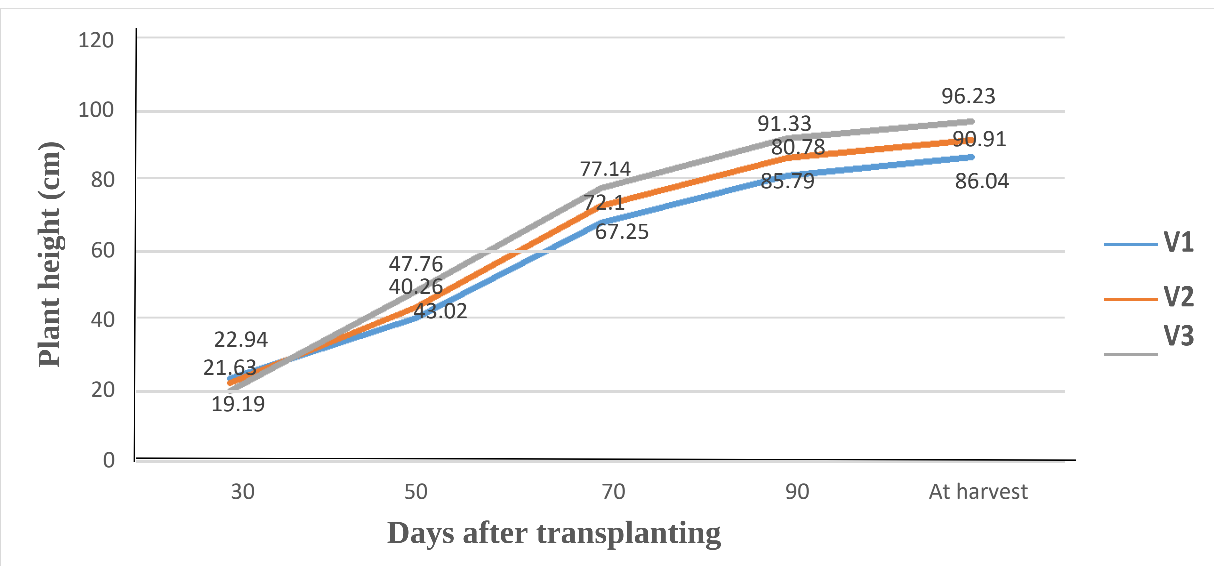
RESULTS AND DISCUSSION

A field experiment was conducted during boro season in 2017-18 to study the "**Influence of zinc application methods on growth and yield of boro rice**". The results of the experiment analyzed statistically are discussed in this chapter with cause, effects and corroborative research findings of the scientists.

4.1 Plant height (cm)

4.1.1 Effect of variety

The data pertaining to plant height of rice at different days after transplantation presented in Figure 2. It can be inferred from the figure that irrespect of varieties of plant height increased gradually upto at harvest. But the rate of increase was much higher upto 70 DAT. After that it reduced slightly. Among the varieties, BRRI hybrid dhan3 (V_3) showed the tallest plant than other tested varieties for all sampling dates except 30 DAT. The difference in plant height of varieties might be due to difference in their genetic makeup. Difference in plant height with different varieties was also observed by Priyadarsini (2001).

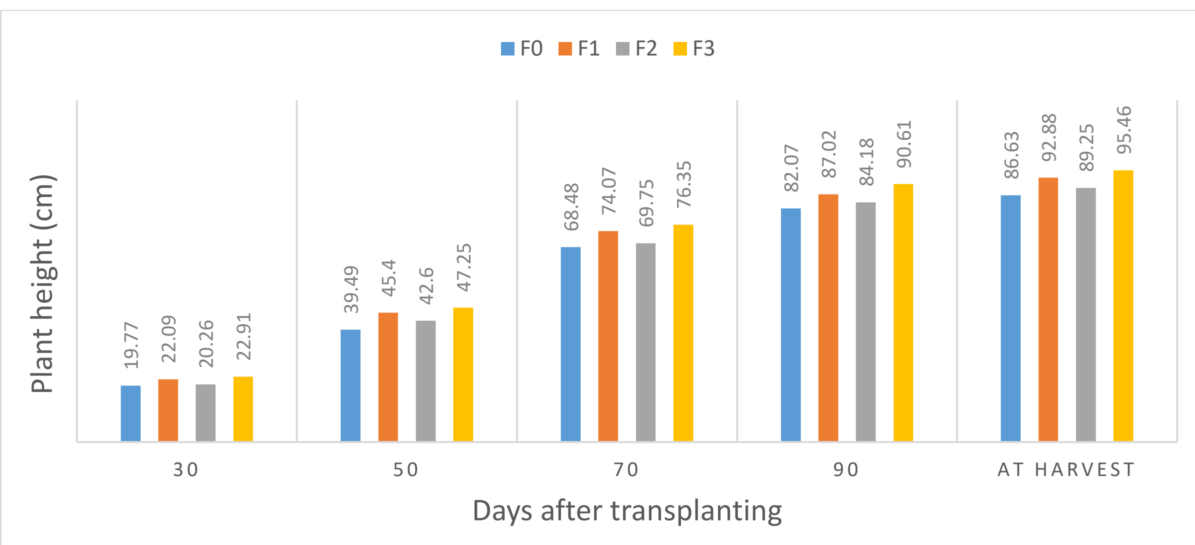


V_1 = BRRI dhan45 V_2 = BRRI dhan63 V_3 = BRRI hybrid dhan3

Figure 2. Effect of variety on plant height (cm) at different days after transplanting of boro rice (SE= 0.617, 0.982, 2.991, 3.462 and 3.303 at 30, 50, 70, 90 DAT and at harvest, respectively)

4.1.2 Effect of Zn application methods

The data regarding the plant height of rice at different days after transplanting (Figure 3) indicated the significant influence by different methods of Zn application. The result of the Figure 3 revealed that the plant height progressively increased with increasing age of the crop. The growth rate was much higher from 30 to 70 DAT. The maximum value of plant height 22.91, 47.25, 76.35, 90.61 and 95.46 cm was observed in soil application (F3) at 30, 50, 70, 90 DAT and at harvest sampling dates, respectively which was statistically similar with root soaking (F1) and foliar application (F2) at 70, 90 DAT and at harvest. But at 30 and 50 DAT the height was statistically similar with root soaking (F1). The shortest plant (19.77, 39.49, 68.48, 82.07 and 86.63 cm) was recorded in no Zn application at 30, 50, 70, 90 DAT and at harvest sampling dates, respectively. The results showed that application of zinc at any method significantly influenced and increased the plant height over no zinc application. Khanda *et al*. (1997) reported that soil application@ 50kg ZnSO4 ha^{-1} increased the plant height significantly over other treatments might be due to more availability of zinc near the rhizosphere which ultimately increased the nutrient content and total uptake. The increase in plant height due to zinc application might be due to it's inter- relationship with auxin production, an important growth promoter regulating the stem elongation and cell enlargement. These results are in agreement with the findings of several scientists like Khan *et al*. (2003) and Zayed *et al*. (2011).



F_0 = No Zinc application (control) F_1 = Root soaking F_2 = Foliar spray F_3 = Soil application

Figure 3. Effect of zinc application methods on plant height (cm) at different days after transplanting of boro rice (SE= 1.191, 1.416, 3.635, 3.703 and 3.781 at 30, 50, 70, 90 DAT and at harvest, respectively)

4.1.3 Interaction effect of variety and Zn application methods

Plant height was significantly influenced by the interaction effect of varieties and Zn application method (Table 2). The tallest plant (51.37, 80.80, 95.66 and 99.23 cm at 50, 70, 90 DAT and at harvest, respectively) was recorded in interaction of BRRI hybrid dhan3 and soil application (V_3F_3) which was statistically similar with V_2F_3, V_3F_1, V_3F_2 at 50 DAT, all combination except V_1F_0, V_1F_2 at 70, 90 DAT and V_1F_0 at harvest.

Table 2. **Interaction of variety and zinc application method on plant height at different days after transplanting of boro rice**

Interaction (Variety × Zn application method)	Plant height (cm) at different days after transplanting				
	30	50	70	90	At harvest
V_1F_0	21.67 a-e	35.33 f	63.47 b	77.60 c	82.40 b
V_1F_1	23.93 ab	43.47 b-d	68.13 ab	81.18 a-c	86.94 ab
V_1F_2	21.97 a-d	38.13 ef	65.93 b	78.47 bc	84.50 ab
V_1F_3	24.20 a	44.13 bc	71.46 ab	85.87 a-c	90.30 ab
V_2F_0	19.87 b-e	38.66 d-f	69.13 ab	81.53 a-c	85.27 ab
V_2F_1	22.60 a-c	44.40 bc	73.47 ab	87.16 a-c	93.97 ab
V_2F_2	20.73 a-e	42.80 c-e	69.00 ab	84.20 a-c	87.53 ab
V_2F_3	23.33 a-c	46.23 a-c	76.80 ab	90.30 a-c	96.86 ab
V_3F_0	17.80 e	44.47 bc	72.84 ab	87.07 a-c	92.23 ab
V_3F_1	19.73 c-e	48.33 ab	80.60 a	92.73 ab	97.73 a
V_3F_2	18.07 de	46.87 a-c	74.33 ab	89.87 a-c	95.73 ab
V_3F_3	21.20 a-e	51.37 a	80.80 a	95.66 a	99.23 a
SE(±)	**2.062**	**2.453**	**6.297**	**6.413**	**6.781**
CV(%)	**11.88**	**6.88**	**10.69**	**9.14**	**8.81**

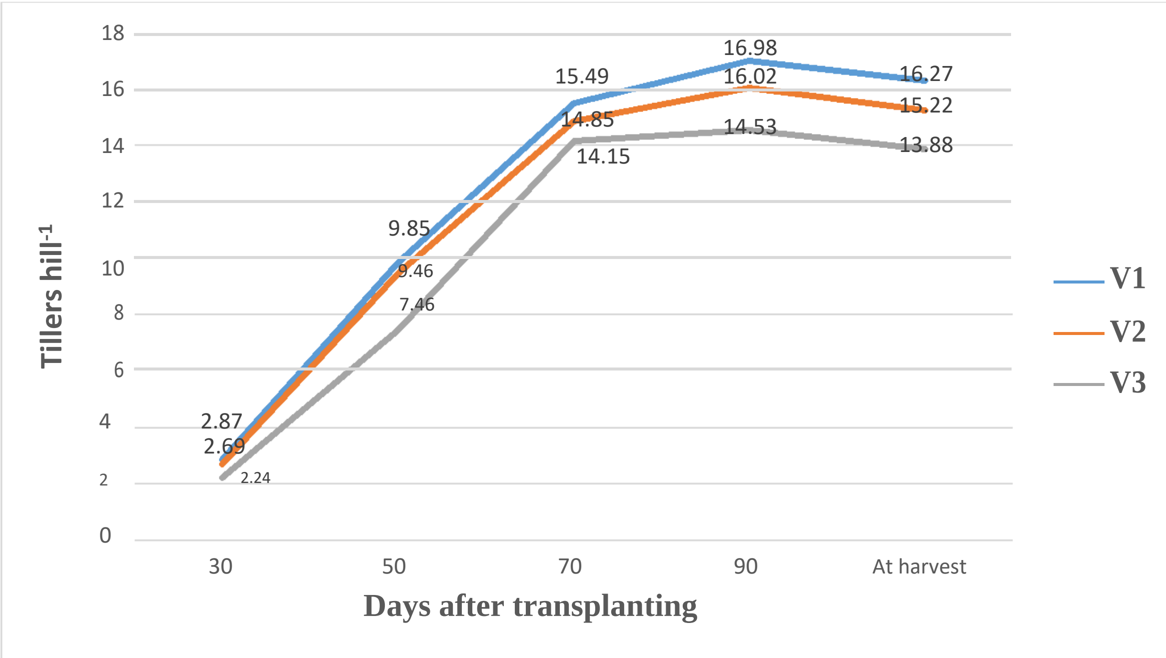
Here, V_1= BRRI dhan45 V_2= BRRI dhan63 V_3= BRRI hybrid dhan3
F_0= No Zinc application (control) F_1= Root soaking F_2= Foliar spray F_3= Soil application NS= Non Significant SE = Standard Error

On the other hand, the shortest value (35.33, 63.47, 77.60 and 82.40 at all sampling dates except 30 DAT) was obtained from BRRI dhan45 and no Zn application (V_1F_0). At 50 DAT the shortest plant was statistically similar with V_1F_2 and V_2F_0. At 70, 90 DAT and at harvest the shortest plant was statistically similar with all combination except V_3F_2 and V_3F_3. At 30 DAT, the longest plant (24.20cm) was observed in V_1F_3 which was statistically similar with V_1F_0, V_1F_1, V_1F_2, V_2F_1, V_2F_2, V_2F_3 and V_3F_3. The shortest plant (17.80 cm) was recorded in V_3F_0 followed by V_3F_2, V_3F_1, V_2F_0, V_2F_2, V_3F_3, and V_1F_0.

4.2 Number of tillers hill^{-1}

4.2.1 Effect of variety

The number of plant tillers hill^{-1} of rice at different days after transplanting as influenced by the varieties are presented in Figure 4. It is noticed that the number of tillers hill^{-1} was increased upto 90 DAT and it reached the highest 16.98 16.02 and 14.53 for V1, V2 and V3, repectively at this samping date (90 DAT). Then number of tillers ware reduced due to dry and rotten of some non-effective tillers. It is also noticed that the number of tillers hill^{-1} rapidly increased from 30 to 70 DAT. Among the tested varieties, the maximum tillers (2.87, 9.85, 15.49, 16.98 and 16.27 at 30, 50, 70, 90 DAT and at harvest sampling dates, respectively) was found in BRRI dhan45 (V1) which was statistically similar with BRRI dhan63 (V2) at all sampling dates which might be due to its higher tillering ability compared to other varieties. The lowest tiller was observed in BRRI hybrid dhan3 (V3) at all sampling dates. The present findings are in accordance with those of Priyadarsini (2001) who reported that different varieties produced different tillers hill^{-1}.

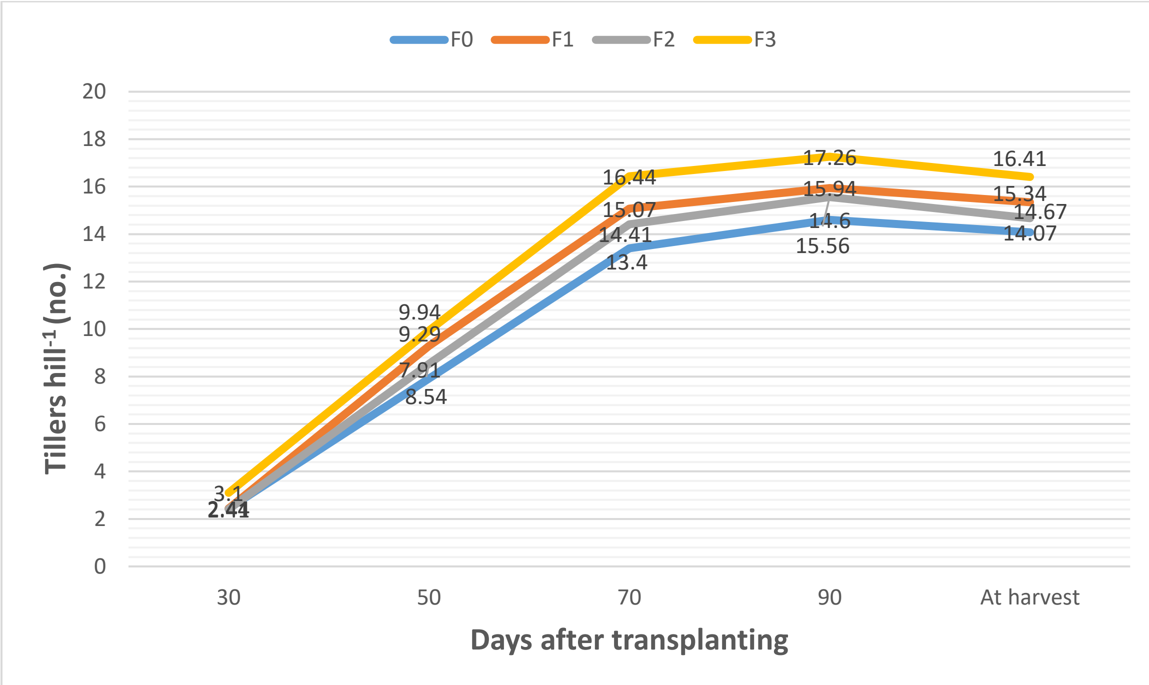


V_1= BRRI dhan45 V_2= BRRI dhan63 V_3= BRRI hybrid dhan3

Figure 4. Effect of variety on tillers hill^{-1} at different days after transplanting of boro rice (SE= 0.085, 0.310, 0.461, 0.574 and 0.326 at 30, 50, 70, 90 DAT and at harvest, respectively).

4.2.2 Effect of Zn application methods

Tiller number hill^{-1} at different growth stages was significantly affected by different methods of Zn application (Figure 5). The figure revealed that the effect Zn application by different methods increased the tiller number over no zinc application. It was also indicated that the tillers hill^{-1} were more increased in soil application compared to root soaking and foliar application of zinc. The maximum tillers (3.10, 9.94, 16.44, 17.26 and 16.41 at 30, 50, 70, 90 DAT and at harvest, respectively) was obtained from soil application (F_3) of zinc. This might be due to quicker and better utilization of zinc through soil application which increased the plant height and leaf area index, which ultimately helped in increasing the photosynthetic rate of plant, which inturn, helped in formation of tillers. The minimum tillers was showed at no Zn application (F_0). These results are in complete agreement with those reported by Ravikiran and Reddy (2004).



F_0= No Zinc application (control) F_1= Root soaking F_2= Foliar spray F_3= Soil application

Figure 5. **Effect of zinc application methods on tillers hill^{-1} at different days after transplanting of boro rice (SE= 0.089, 0.555, 0.611, 0.643 and 0.4610 at 30, 50, 70, 90 DAT and at harvest, respectively).**

4.2.3 Interaction effect of variety and Zn application methods

Interaction of variety and Zn application method was observed significantly positive effect on number of tillers hill^{-1} at all growth stage (Table 3). The maximum tillers hill^{-1} (3.67, 11.53, 17.53, 18.8 and 18.03 at 30, 50, 70, 90 DAT and at harvest, respectively) was observed in interaction treatment of BRRI dhan45 and soil application (V_1F_3) compared to others interactions. The lowest tillers hill^{-1} (6.73, 12.40, 13.27 and 12.93 at 50, 70, 90 DAT and at harvest, respectively) was noticed in interaction of BRRI hybrid dhan3 and no Zn application (V_3F_0). At 30 DAT, the lowest tillers hill^{-1} (2.03) was recorded at V_3F_2.

Table 3. **Interaction of variety and zinc application method on tillers hill^{-1} at different days after transplanting of boro rice**

Interaction (Variety × Zn application method)	Tillers hill^{-1} (no.) at different days after transplanting				
	30	50	70	90	At harvest
V_1F_0	2.47 b-c	8.40 b-d	14.40 b-d	15.63 b-e	15.13 cd
V_1F_1	2.60 bc	10.13 ab	14.93 bc	17.20 a-c	16.93 ab
V_1F_2	2.73 b	9.33 bc	15.10 bc	16.30 b-d	15.00 cd
V_1F_3	3.67 a	11.53 a	17.53 a	18.80 a	18.03 a
V_2F_0	2.37 c-e	8.60 b-d	13.40 cd	14.90 c-e	14.17 de
V_2F_1	2.60 bc	9.83 a-c	15.00 bc	15.70 b-e	15.13 cd
V_2F_2	2.47 a	9.27 bc	14.33 cd	15.83 b-d	15.32 b-d
V_2F_3	3.33 b-c	10.13 ab	16.67 ab	17.67 ab	16.27 bc
V_3F_0	2.50 bc	6.73 d	12.40 d	13.27 e	12.93 e
V_3F_1	2.12 de	7.90 cd	15.27 a-c	14.93 c-e	13.97 de
V_3F_2	2.03 e	7.03 d	13.80 cd	14.57 de	13.69 de
V_3F_3	2.30 c-e	8.17 cd	15.13 bc	15.33 b-e	14.93 cd
SE(±)	**0.154**	**0.962**	**1.069**	**1.114**	**0.798**
CV(%)	**7.25**	**13.20**	**8.83**	**8.61**	**6.46**

Here, V_1= BRRI dhan45 V_2= BRRI dhan63 V_3= BRRI hybrid dhan3

F_0= No Zinc application (control) F_1= Root soaking F_2= Foliar spray F_3= Soil application

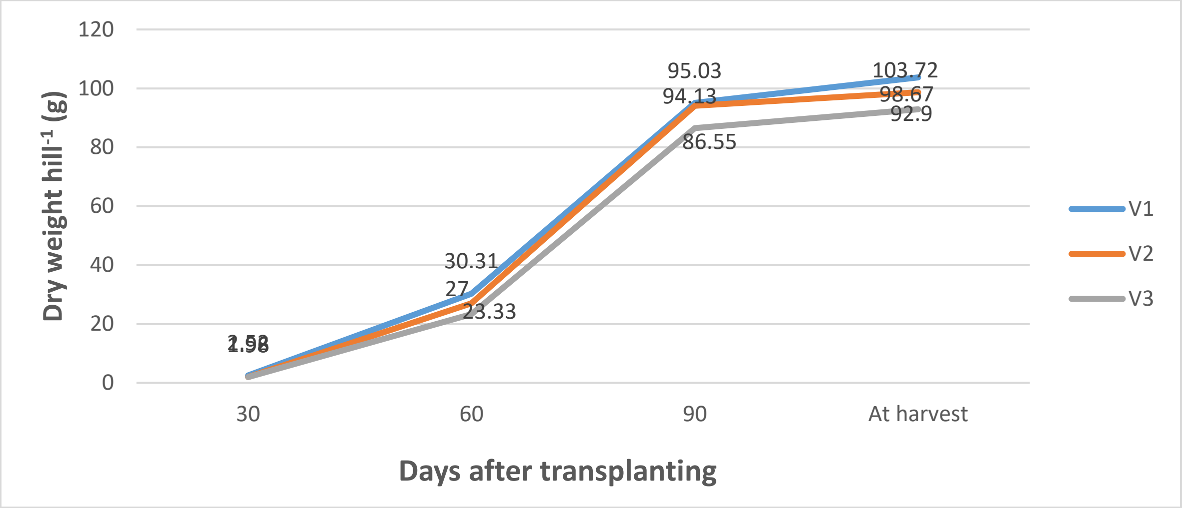
NS= Non Significant SE = Standard Error

4.3 Dry weight hill^{-1} (g)

4.3.1 Effect of variety

The data regarding to dry weight hill^{-1} of rice at different days after transplantation shown in Figure 6. It can be inferred from the figure that irrespective of varieties of dry weight hill^{-1} increased rapidly upto at 90 DAT. But the rate of increase was much higher from 60 to 90 DAT. After that the rate of increase was much slower. Among the tested varieties, BRRI dhan45 (V1) showed the tallest plant than other tested varieties for all sampling dates. Higher plant height

(Figure 2) and tiller number (Figure 4) might have been responsible for variation in dry matter production among the varieties. Similar results on dry matter production of varieties at all stages of sampling were reported by Tomar *et al*. (1994). The lowest dry weight hill^{-1} was obtained from BRRI hybrid dhan3 (V3) at all sampling dates.



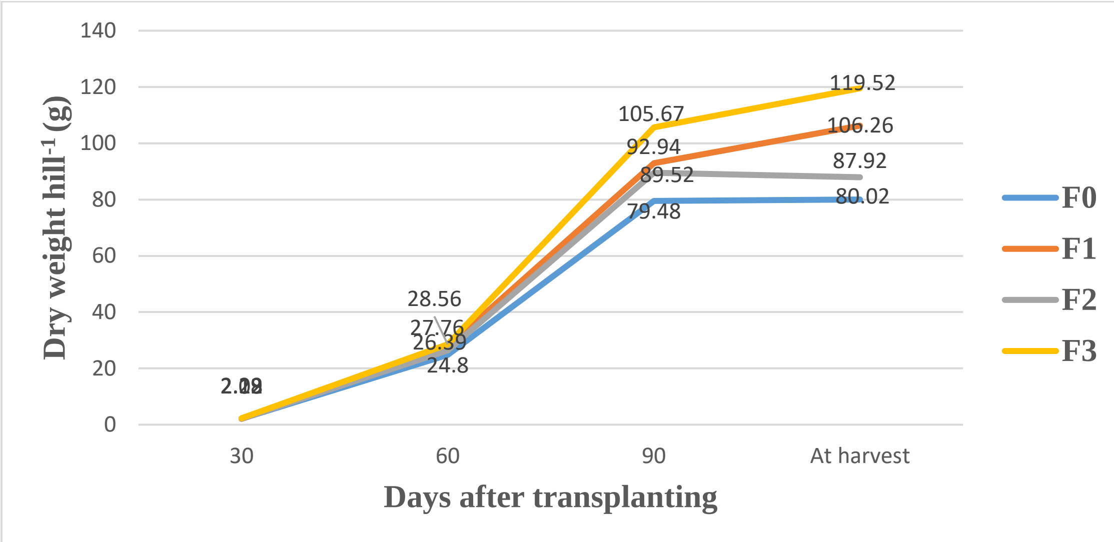
V_1= BRRI dhan45 V_2= BRRI dhan63 V_3= BRRI hybrid dhan3

Figure 6. Effect of variety on dry weight hill^{-1} at different days after transplanting of boro rice (SE= 0.064, 1.346, and 3.876 at 30, 60, 90 DAT and at harvest, respectively).

4.3.2 Effect of Zn application methods

The data on dry weight hill^{-1} at different growth stages was significantly affected by different methods of Zn application has been shown in Figure 7. It revealed from the figure that the effect Zn application by different methods increased the dry weight hill^{-1} over no zinc application. The figure also indicated that dry weight hill^{-1} were more increased in soil application (F_3) compared to root soaking (F_1) and foliar application (F_2) of zinc at 90 DAT and at harvest samling dates. The maximum dry weight (2.29, 28.56, 105.67 119.52 g at 30, 60, 90 DAT and at harvest, respectively) was obtained from soil application (F_3) of zinc this might be due to higher availability of zinc i.e. the yield limiting nutrient in rhizosphere immediately after transplanting. Significant increase in dry matter production with soil application of ZnSO4 was also observed by several researchers such as Kulandaivel *et al*. (2004) and Mustafa *et al*. (2011).

The minimum tillers was observed at no Zn application.



F_0= No Zinc application (control) F_1= Root soaking F_2= Foliar spray F_3= Soil application

Figure 7. Effect of zinc application methods on dry weight hill^{-1} at different days after transplanting of boro rice (SE= NS, 0.524, 3.360 and 3.684 at 30, 60, 90 DAT and at harvest, respectively)

4.3.3 Interaction effect of variety and Zn application methods

Interaction between variety and Zn application methods was affected significantly on dry weight hill^{-1} at all sampling dates (Table 4). The highest dry weight hill^{-1} (2.55, 31.67, 108.79 and 128.28g at 30, 60, 90 DAT and at harvest, respectively) was obtained from the interaction treatment of BRRI dhan45 and soil application (V_1F_3) compared to others interactions. The lowest dry weight hill^{-1} (19.31, 78.13, and 77.09g at 50, 70, 90 DAT and at harvest, respectively) was recorded in interaction of no Zn application and BRRI hybrid dhan3 (V_3F_0). At 30 DAT, the minimum dry weight hill-1 (1.83g) was recorded at V_2F_1.

Table 4. **Interaction of variety and zinc application method on dry weight hill^{-1} at different days after transplanting of boro rice**

Interaction (Variety × Zn application method)	Dry weight (g hill^{-1}) at different DAT			
	30	60	90	At harvest
V_1F_0	2.52 a	28.96 bc	78.42 f	82.74 f
V_1F_1	2.55 a	29.94 a-c	98.64 a-c	112.43 bc
V_1F_2	2.50 a	30.65 ab	94.28 b-e	90.89 d-f
V_1F_3	2.55 a	31.67 a	108.79 a	128.82 a
V_2F_0	1.94 b	26.14 c	81.90 ef	80.22 f
V_2F_1	1.83 b	27.39 bc	96.06 a-d	105.92 cd
V_2F_2	1.93 b	27.17 bc	92.64 c-e	87.34 ef
V_2F_3	2.23 ab	27.33 bc	105.92 ab	121.2 ab
V_3F_0	1.92 b	19.31e	78.13 f	77.09 f
V_3F_1	1.88 b	25.94 c	84.13 d-f	100.43 c-e
V_3F_2	1.95 b	21.37 d	81.63 ef	85.53 f
V_3F_3	2.10 b	26.69 bc	102.30 a-c	108.55 bc
SE(±)	**0.193**	**0.907**	**5.819**	**6.380**
CV(%)	**10.95**	**4.13**	**7.76**	**7.94**

Here, V_1= BRRI dhan45 V_2= BRRI dhan63 V_3= BRRI hybrid dhan3

F_0= No Zinc application (control) F_1= Root soaking F_2= Foliar spray F_3= Soil application

NS= Non Significant SE = Standard Error

4.4 Number of effective tillers hill^{-1}

4.4.1 Effect of variety

The data regarding the number of effective tillers hill^{-1} (Table 5) exerted significant influence due to varieties used in the present study (Table 5). The highest effective tillers hill^{-1} (13.98) was observed in BRRI dhan45 (V_1) which was statistically similar with BRRI dhan63 (V_2) and the lowest (11.90) effective tillers hill^{-1} was recorded in BRRI hybrid dhan3 (V_3). It can be inferred from the result that V_1 (BRRI dhan45) was superior than V_3 (BRRI hybrid dhan3) by producing 17.48% higher effective tillers hill^{-1}. This might be due to its high tillering ability and conversion of total number of tillers into more effective tillers. The results were in conformity with the findings of Sharma *et al*. (1999).

4.4.2 Effect of Zn application method

Effective tillers hill^{-1} of rice differed significantly due to zinc application methods on rice (Table 6). The maximum effective tillers hill^{-1}(14.49) was obtained from soil application of zinc (F_3) and the lowest (10.91) was observed in no Zn application (F_0) which indicate that F_3 (soil application produced 32.8% higher effective tillers hill^{-1} than F_0 (no Zn application) treatment and that was 7.57% higher than F_1 (root soaking) application methods. This increase of effective tillers at soil application of zinc might be due to increased photosynthetic rate, excessive accumulation of sucrose, glucose and fructose in plant, which might have increased the physiological parameters of the plant. The present findings are in accordance with those of Chaudary and Sinha (2007). The lower number of effective tillers can be attributed to lower uptake of zinc in F_0, which became limiting nutrient uptake.

Table 5. **Effect of varieties on yield attributes on boro rice**

Variety	**Effective tillers hill^{-1} (no.)**	**Non effective tillers hill^{-1} (no.)**	**Panicle length (cm)**	**Filled grains panicle^{-1} (no.)**	**Unfilled grains panicle^{-1} (no.)**	**Weight of 1000 seed (g)**
V_1	13.98 a	2.45 a	22.90 ab	79.68 b	11.34 a	24.96 b
V_2	13.01 ab	2.23 b	21.69 b	80.72 b	8.61 b	23.26 b
V_3	11.90 b	1.98 c	23.48 a	100.33 a	6.84 c	29.33 a
SE(±)	**0.511**	**0.069**	**0.512**	**3.020**	**0.489**	**0.897**
CV(%)	**9.66**	**7.68**	**5.52**	**8.51**	**13.42**	**8.50**

V_1= BRRI dhan45 V_2= BRRI dhan63 V_3= BRRI hybrid dhan3 SE = Standard Error

Table 6. **Effect of Zinc application methods on yield attributes on boro rice**

Zn application method	Effective tillers hill^{-1} (no.)	Non effective tillers hill^{-1} (no.)	Panicle length (cm)	Filled grains panicle^{-1} (no.)	Unfilled grains panicle^{-1} (no.)	Weight of 1000 seed (g)
F_0	10.91 c	3.28 a	21.73 b	79.45 c	11.03 a	24.28 b
F_1	13.47 b	1.77 b	23.03 ab	89.31 ab	7.87 c	26.42 a
F_2	12.98 b	1.90 b	22.32 ab	85.24 b	9.48 b	25.67 ab
F_3	14.49 a	1.92 b	23.69 a	93.65 a	7.32 c	27.03 a
SE(±)	**0.3729**	**0.0748**	**0.8289**	**2.5294**	**0.5382**	**0.9531**
CV(%)	**6.10**	**7.16**	**7.75**	**6.17**	**12.79**	**7.84**

F_0= No Zinc application (control) F_1= Root soaking F_2= Foliar spray F_3= Soil application

SE = Standard Error

4.4.3 Interaction effect of variety and Zn application method

Data on the number of effective tillers hill^{-1} are shown in Table 7, which was significantly influenced by interaction effect of varieties and Zn application method. Results revealed that the highest effective tillers hill^{-1} (16.10) was observed in V1F3 which was significantly different from all other treatment combinations. The lowest number of effective tillers hill^{-1} (10.40) was obtained from V2F0 which was statistically similar with V3F0 and V1F0.

4.5 Number of non effective tillers hill^{-1}

4.5.1 Effect of variety

The number of non-effective tiller hill^{-1} was significantly influenced due to different varieties (Table 5). Result revealed that the maximum non effective tillers hill^{-1} (2.45) was observed in BRRI dhan45 (V1) and the lowest non effective tillers hill^{-1} (1.98) was obtained from BRRI hybrid dhan3 (V3) which indicated that V_3 produced 19.18% lower non effective tillers hill^{-1} than V_1.

4.5.2 Effect of Zn application methods

The data of non effective tiller hill^{-1} of boro rice as affected by different methods of Zn application are presented in Table 6. Result noticed that the non effective tiller hill^{-1} decreased significantly by Zn application. The maximum number of non effective tiller hill^{-1}(3.28) was observed in no zinc application (F_0) and the lowest (1.77) at root soaking application (F_1).

4.5.3 Interaction effect of variety and Zn application methods

Interaction effect of variety and Zn application method significantly influenced the number of non-effective tillers hill^{-1} (Table 7). The maximum non effective tillers hill^{-1} (3.77) was obtained from BRRI dhan45 and soil application of Zn (V_1F_3) followed by V_1F_0 (3.66) and the lowest number of non-effective tillers hill^{-1} (1.50) was recorded in V_2F_2 which was statistically similar with V_2F_1 (1.56) and V_3F_1 (1.54) and V_3F_3 (1.76).

4.6 Panicle length (cm)

4.6.1 Effect of variety

Panicle length was significantly affected by rice varieties (Table 6). The longest panicle (23.48 cm) was obtained from BRRI hybrid dhan3 (V_3) followed by BRRI dhan45 (V_1). The shortest panicle was found in BRRI dhan63 (V_2). This may due to the genetic makeup of varieties that panicle length vary with variety to variety among the varieties.

4.6.2 Effect of Zn application methods

Significant differences were noticed in respect of panicle length in rice due to different methods of Zn application (Table 6). Among themethods of Zn application , the tallest panicle (23.69cm) was recorded in soil application (F_3) which was statistically similar with root soaking (F_1) and foliar application (F_2) of Zn. The shortest panicle obtained from no zinc application (F_o). The increase of panicle length could be ascribed to the adequate supply of zinc resulting in improvement in crop growth. Similar result was reported by Bodruzzaman *et al*., (2007), and Khan *et al.*, (2007) in which the adequate supply of zinc results in the greater panicle length.

4.6.3 Interaction effect of variety and Zn application method

Panicle length was significantly influenced by the interaction effect of variety and Zn application method in boro rice (Table 7). The longest panicle (24.15 cm) was recorded in BRRI hybrid dhan3 and soil application (V_3F_3) which was statistically similar with all combination except V_2F_0 and

V_2F_2. On the other hand, the lowest panicle length was obtained from no Zn application and BRRI dhan63 (V_2F_0) which was statistically similar with all combination except V_1F_3, V_3F_0 and V_3F_3.

4.7 Filled grains panicle^{-1} (no)

4.7.1 Effect of variety

Number of filled grain panicle^{-1} differed significantly due to varieties (Table 5). Significantly the highest number of filled grains was recorded in BRRI hybrid dhan3 (V3). Than other two tested varieties, which was 24.61% and 24.29% higher than BRRI dhan45 and BRRI dhan63, respectively. Variation in grains panicle^{-1} might be due to difference in panicle size of the varieties, which is a genetic character and specific to each variety. Similar relation with different varieties on total grains panicle^{-1} were reported by Sharma *et al*. (1999).

4.7.2 Effect of Zn application methods

Filled grains panicle^{-1} affected signifintly due to methods of Zn application in rice (Table 6) which indicated that zinc fertilization by all the three methods increased the number of filled grains panicle^{-1} significantly over no Zn application. The maximum value of filled grains panicle^{-1} (93.65) was recorded in soil application (F3) followed by root soaking (F1). This might be due to higher zinc supply from ZnSO4H2O which is evidenced from higher total Zn uptake. These results are in conformity with the findings of Chaudary *et al*. (2007) and Reddy *et al*. (2011). The lowest value (79.45) of filled grains panicle^{-1} was recorded in no Zn application (F0).

4.7.3 Interaction effect of variety and Zn application methods

Data regarding on the number of filled grains hill^{-1} are noticed in Table 7 which was significantly influenced by interaction effect of varieties and Zn application method. Results revealed that the highest filled grains hill^{-1} (105.51) was recorded with V_3F_3 followed by V_3F_1, V_3F_2. The lowest filled grains hill^{-1} (71.19) was obtained from V_2F_0 which was statistically similar with V_3F_0.

4.8 Unfilled grains panicle^{-1} (no)

4.8.1 Effect of variety

The data pertaining to number of unfilled grains panicle^{-1} as influenced by varieties has been presented in the Table 5. Significantly the highest number of unfilled grains panicle^{-1} (11.34) was recorded in BRRI dhan45 (V_1) and the lowest in BRRI hybrid dhan3 (V_3)

4.8.2 Effect of Zn application methods

Unfilled grains panicle^{-1} differed significantly due to different methods of Zn application (Table 6). The result indicated that zinc applied irrespective of reduced the number of unfilled grains significantly than no Zn application treatment. The highest unfilled grains panicle^{-1} (11.03) was recorded in no Zn application (F_0). The lowest value of unfilled grains panicle^{-1} (7.32) was recorded in soil application (F_3) followed by root soaking (F_1). The similar trend has been found in the findings of Hernandez *et al*. (1988).

4.8.3 Interaction effect of variety and Zn application methods

Unfilled grains panicle^{-1} of boro rice differed significantly due to interaction effect of varieties and Zn application method (Table 7). The highest unfilled grains panicle^{-1} (14.95) was recorded with the interaction of BRRI dhan45 and no Zn applied (V_1F_0) which was significantly different from all other treatment combinations, whereas, the minimum value of unfilled grains panicle^{-1} (5.59) was recorded from V_3F_3 treatment followed by V_3F_1 and V_2F_3.

4.9 Weight of 1000 seeds (g)

4.9.1 Effect of variety

Weight of 1000-seed of rice was significantly affected due to varieties (Table 5). The highest 1000-seed weight (29.33g) was found with BRRI hybrid dhan3 (V_3). This might be due to the bold size of the grain. Sharma *et al*. (1999) also reported variation in grain weight among the varieties. The lowest seed weight (23.26g) was observed with BRRI dhan63 (V_2), which might be due to the fact that BRRI dhan63 (V_2) being a fine quality rice grain recorded the lower 1000-grain weight.

4.9.2 Effect of Zn application methods

The 1000 grain weight of rice was influenced significantly due to the different methods of zinc application (Table 6). Application of Zn increased the 1000 grain weight significantly over control (no Zn application). The highest 1000 grain weight (27.03g) was recorded in soil application (F_3) which was statistically similar with root soaking (F_1) and foliar application (F_2). This increase in seed weight upon zinc fertilization could be attributed to enhanced zinc uptake and translocation of sugars and higher carbohydrate accumulation in seed. Similar results have been reported by Anand *et al.* (2007) and Abdoli *et al*. (2014). The lowest value (24.28g) of 1000 grain weight was recorded in no Zn application (F_0) followed by foliar application (F_2).

4.9.3 Interaction effect of variety and Zn application methods

Interaction effect of varieties and Zn application method significantly influenced on 1000-seed weight (Table 7). Results indicated that the highest 1000-seed weight (30.38 g) was with interaction of V_3F_3 which was statistically similar with V_3F_0, V_3F_1 and V_3F_2. On the other hand, the lowest result was obtained from V_2F_0 (21.04 g) which was closely followed by V_2F_2, V_2F_1, V_1F_0, V_1F_2, and V_3F_3.

Table 7. **Interaction of variety and zinc application method on yield attributes on boro rice**

Interaction (variety × Zn application method)	Effective tillers hill^{-1} (no)	Non effective tillers hill^{-1} (no)	Panicle length (cm)	Filled grains panicle^{-1} (no)	Unfilled grains panicle^{-1} (no)	Weight of 1000 seeds (g)
V_1F_0	11.80 d-f	3.66 a	22.07 a-c	75.93 de	14.95 a	23.80 ef
V_1F_1	14.40 b	2.20 bc	23.13 a-c	81.49 b-e	9.15 c-e	25.40 c-e
V_1F_2	13.60 bc	2.00 cd	22.60 a-c	76.01 de	11.52 b	24.21 d-f
V_1F_3	16.10 a	1.93 cd	23.80 ab	85.32 bc	9.72 b-d	26.44 b-e
V_2F_0	10.40 f	3.77 a	20.59 c	71.19 e	10.38 bc	21.04 f
V_2F_1	13.57 b-d	1.56 e	21.95 a-c	83.53 b-d	7.78 d-f	23.98 ef
V_2F_2	13.87 bc	1.50 e	21.11 bc	78.03 c-e	9.62 b-d	23.76 ef
V_2F_3	14.20 bc	2.07 c	23.10 a-c	90.13 b	6.64 fg	24.26 d-f
V_3F_0	10.53 f	2.40 b	22.53 ab	91.23 b	7.76 d-f	28.01 a-d
V_3F_1	12.43 c-e	1.54 e	23.99 a-c	102.91 a	6.69 fg	29.87 ab
V_3F_2	11.47 ef	2.20 bc	23.24 a-c	101.68 a	7.30 e-f	29.05 a-c
V_3F_3	13.17 b-d	1.76 de	24.15 a	105.51 a	5.59 g	30.38 a
SE(±)	**0.646**	**0.130**	**1.436**	**4.381**	**0.932**	**1.651**
CV(%)	**6.10**	**7.16**	**7.75**	**6.17**	**12.79**	**7.84**

Here, V_1= BRRI dhan45 V_2= BRRI dhan63 V_3= BRRI hybrid dhan3

F_0= No Zinc application (control) F_1= Root soaking F_2= Foliar spray F_3= Soil application

NS= Non Significant SE = Standard Error

4.10 Grain yield (t ha^{-1})

4.10.1 Effect of variety

Grain yield of boro rice exerted significant variation due to varieties (Table 8). Among the varieties, BRRI hybrid dhan3 (V_3) out yielded over BRRI dhan45 (V_1) and BRRI dhan63 (V_2) by producing 40.46% and 35.96% higher yield. However, BRRI hybrid dhan3 (V_3) produced significantly the highest yield (8.47 t ha^{-1}) and that of the lowest (6.03 t ha^{-1}) was observed from BRRI dhan45 (V_1). The higher grain yield in BRRI hybrid dhan3 could be attributed to higher panicle length, filled grains $panicle^{-1}$ and 1000-seed weight compared to BRRI dhan63 (V_2) and BRRI dhan45 (V_1). The result corroborates with the findings of Priyadarsini (2001) and Dhaliwal *et al*. (2010) who observed yield variation among the varieties.

4.10.2 Effect of Zn application methods

The influence of methods of Zn application on grains yield of rice showed significant variation (Table 9). The results indicated that the different methods of Zn application significantly increased the grain yield compared to no Zn application (F_0). The highest grain yield (7.53 t ha^{-1}) was recorded with soil application of Zn (F_3) which was statistically similar with root soaking (F_1). The increased yield with Zn application might be attributed to enhance yield components viz., number of effective tillers, panicle length, and number of filled grains $panicle^{-1}$, seed weight, and reduced number of unfilled grains $panicle^{-1}$ and faster grain filling. The increase in yield might also be attributed to the better supply of Zn, which might have played specific role in various metabolic activities. These results are in complete agreement with the findings of Ravikiran and Reddy (2004). The lowest grain yield of 6.21 t ha^{-1} was recorded with no Zn application (F_0) which was statistically similar with foliar application (F_2) might be due to significant reduction in yield components as a result of limitation in zinc availability to rice crop.

Table 8. **Effect of variety on grain yield, straw, biological yield and harvest index of boro rice**

Variety	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
V_1	6.03 b	6.75 b	12.77 b	47.53
V_2	6.23 b	6.81 b	13.05 b	47.53
V_3	8.47 a	9.10 a	17.57 a	48.20
SE(±)	**0.236**	**0.558**	**0.676**	**NS**
CV (%)	**8.37**	**18.11**	**11.46**	**6.89**

Here, V_1 = BRRI dhan45 V_2 = BRRI dhan63 V_3 = BRRI hybrid dhan3
NS = Non Significant SE = Standard Error

4.10.3 Interaction effect of variety and Zn application method

Interactions of varieties and Zn application method had a significant influence on the grain yield of boro rice (Table 10). It was observed that V_3F_3 treatment interaction produced the highest grain yield (8.90 t ha^{-1}) of boro rice which was statistically similar with V_3F_0, V_3F_1 and V_3F_2 interaction. However, the lowest grain yield (5.32 t ha^{-1}) was recorded in V_1F_0 which was statistically similar with V_2F_0, V_2F_2, V_1F_1 and V_1F_2.

4.11 Straw yield (t ha^{-1})

4.11.1 Effect of variety

Straw yield of rice differed significantly due to tested varieties (Table 8). Higher straw yield of 9.10 t ha^{-1} was recorded with BRRI hybrid dhan3 (V_3) compared to BRRI dhan63 (V_2) and BRRI dhan45 (V_1). Significant effect on straw yield of varieties might be due to their significant influence on plant height and bold tiller. The result agreed with the finding of Priyadarsini (2001) where grain yield of rice varied among the varieties.

4.11.2 Effect of Zn application methods

Methods of Zn application exerted significant affect on straw yield of rice (Table 9). The highest straw yield (8.00 t ha^{-1}) was measured with F_3 (soil application on Zn) treatment which was statistically similar with F_2 (foliar spray Zn application). The lowest straw yield (7.07 t ha^{-1}) was measured with F_0 (no Zn application). It can be inferred from the result that F_3 (soil application on Zn) treatment was superior over F_0 (no Zn application) by producing 0.93 t ha^{-1} higher straw yield. Increase in the straw yield with soil application of Zn was reported by many scientists like Kulandaivel *et al*. (2003), Mythili *et al.* (2003) and Singh *et al.* (2006)**.**

4.11.3 Interaction effect of variety and Zn application methods

Straw yield was significantly influenced by the interaction of varieties and Zn application method (Table 10). The highest straw yield (9.31 t ha^{-1}) of boro rice was recorded in the interaction of BRRI hybrid dhan3 and soil application (V_3F_3) which was identical to V_3F_3 and statistically similar with V_3F_0, V_3F_1, and V_3F_2. The lowest straw yield (6.17 t ha^{-1}) of boro rice was recorded in V_1F_0 which was statistically identical with V_2F_0, V_1F_2 and similar with V_2F_2, V_2F_3, and V_1F_2. This result was in agreement with the finding of Patel (2000) who reported that straw yield performance varied with varieties.

4.12 Biological yield (t ha^{-1})

4.12.1 Effect of variety

Biological yield of rice was significantly influenced by the variety (Table 8). The highest biological yield (17.57 t ha^{-1}) was obtained from BRRI hybrid dhan3 (V_3) and the lowest (12.77 t ha^{-1}) from the BRRI dhan45 (V_1) followed by BRRI dhan63 (V_2). Rahman (2001) reported that hybrid variety produced higher biological yield compared to inbred variety due to its hybrid variety higher grain yield and straw yield.

4.12.2 Effect of Zn application methods

Significant differences were noticed in respect of biological yield due to different methods of Zn application (Table 9). Among the different treatments, the highest biological yield (15.45 t ha^{-1}) was recorded in soil application of Zn (F_3) which was statistically similar with root soaking (F_1) and foliar application of Zn (F_2). The lowest biological yield (13.28 t ha^{-1}) obtained from no Zn application (F_3).

Table 9. **Effect of Zinc application methods on on grain yield, straw, biological yield and harvest index of boro rice**

Zn application method)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
F_0	6.21 c	7.07 c	13.28 b	46.71
F_1	7.28 ab	7.21 bc	15.28 a	48.17
F_2	6.62 bc	7.91 ab	13.84 ab	47.73
F_3	7.53 a	8.00 a	15.45 a	48.69
SE(±)	**0.349**	**0.306**	**0.909**	**NS**
CV(%)	**10.71**	**18.89**	**13.34**	**7.12**

F_0= No Zinc application (control) F_1= Root soaking F_2= Foliar spray F_3= Soil application

NS= Non Significant SE = Standard Error

4.12.3 Interaction effect of variety and Zn application methods

Biological yield was influenced significantly due to interaction effect of varieties and Zn application methods (Table 9). The maximum biological yield (18.09 t ha^{-1}) was obtained from V_3F_1 and V_3F_3 which was statistically similar with V_3F_0 and $V3F_2$. The lowest biological yield (11.49 t ha^{-1}) was recorded in V_1F_0 which was statistically similar with all combination except V_3F_3, V_3F_1, V_3F_2, V_3F_0. The result agreed with the findings of Ahmed *et al.* (2005) who observed the effect of zinc on biological yield (15 t ha^{-1}) of rice. This result was shown due to cause of higher grain and straw yield of BRRI hybrid dhan3 than other test varieties under the present study. Nirmaladevi (2001) reported that hybrid variety produced higher biological yield compared to inbred variety.

4.13 Harvest index (%)

4.13.1 Effect of variety

Statistically analyzed data on harvest index are presented in Table 8. The result revealed that harvest index was non-significant regarding the varieties but numerically higher in BRRI hybrid dhan3 (V_3) than BRRI dhan63 (V_2) and BRRI dhan45 (V_1).

4.13.2 Effect of Zn application methods

Statistically analyzed data on harvest index are presented in Table 9. Perusal of the harvest index data indicate non-significant as influenced by different methods of zinc application but numerically the highest (48.69%) was recorded in soil application (F_3). It might be due to increased efficiency in converting dry matter into grain by the soil application of zinc. The lowest harvest index (46.71%) was recorded in the treatment where no zinc was applied (F_0).

4.13.3 Interaction effect of variety and Zn application methods

Harvest index was not significantly influenced by interaction effect of varieties and Zn application methods (Table 10). But numerically the maximum harvest index (49.04 %) was observed in interaction of soil application and BRRI hybrid dhan3 (V_3F_3). The lowest (46.28%) was reported in no Zn application and BRRI dhan45 (V_1F_0).

Table 10. **Interaction of variety and Zinc application method on on grain yield, straw, biological yield and harvest index of boro rice**

Interaction (variety × Zn application method)	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest index (%)
V_1F_0	5.32 d	6.17 c	11.49 d	46.28
V_1F_1	6.28 cd	7.30 a-c	13.58 cd	47.95
V_1F_2	5.69 cd	6.23 c	11.92 d	47.53
V_1F_3	6.82 bc	7.29 a-c	14.11 b-d	48.37
V_2F_0	5.42 d	6.17 c	11.59 d	46.73
V_2F_1	6.78 bc	7.39 a-c	14.16 b-d	48.02
V_2F_2	5.86 cd	6.42 bc	12.28 d	47.53
V_2F_3	6.88 bc	7.28 bc	14.16 b-d	48.65
V_3F_0	7.88 ab	8.89 ab	16.77 a-c	47.12
V_3F_1	8.78 a	9.31 a	18.09 a	48.53
V_3F_2	8.32 a	9.01 ab	17.33 ab	48.12
V_3F_3	8.90 a	9.19 a	18.09 a	49.04
SE(±)	**0.6045**	**1.1649**	**1.5750**	**NS**
CV (%)	**10.71**	**18.89**	**13.34**	**7.12**

Here, V_1= BRRI dhan45 V_2= BRRI dhan63 V_3= BRRI hybrid dhan3

F_0= No Zinc application (control) F_1= Root soaking F_2= Foliar spray F_3= Soil application

NS= Non Significant SE = Standard Error

CHAPTER 5

SUMMARY AND CONCLUSIONS

A field experiment entitled "Influence of zinc application methods on growth and yield of boro rice" was carried out under field conditions during boro season 2017-18 at the Agronomy field of Sher-e-Bangla Agricultural University, Dhaka -1207. The experiment consisted of two factors viz. (1) Factor A - variety; i. BRRI dhan45 (V1), ii. BRRI dhan63 (V2) and iii. BRRI hybrid dhan3 (V3) and (2) Factor B – Zn application methods; i. No Zinc application (F0) ii. Root Soaking (F1) iii. Foliar spray (F2) iv. Soil application (F3). The experiment was laid out in a split-plot design with three replications having variety in the main plots and Zn application methods in the sub-plot. There were 12 treatment combinations. The total numbers of unit plots were 36. All recorded data are subjected to statistical analysis using analytical computer software program statistix-10. The mean differences among the treatments were compared by least significant difference test (LSD) at 5% level of significance.

The weather during the crop growing period did not exhibit any major fluctuations and was congenial for crop growth. A total rainfall of 302 mm was received in 27 rainy days during the investigation period, which was insufficient for rice crop. Hence, need based irrigations were given to avoid moisture stress.

The observations were recorded on plant height (cm), number of tillers hill^{-1}(no), dry weight hill^{-1} (g), panicle length (cm), effective tillers hill^{-1}, non-effective tillers hill^{-1}, filled grains panicle^{-1}, unfilled grains panicle^{-1}, weight of 1000 seed (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield(t ha^{-1}) and harvest index(%).

The effect of variety on plant height showed dissimilar at different growth stage. BRRI hybrid dhan3 (V_3) showed the tallest plant (47.76, 77.14, 91, 33, and 96.23 cm at 50, 70, 90 DAT and at harvest, respectively) where BRRI dhan45 (V_1) showed the shortest plant 40.26, 67.25, 80.78 and 86.04 cm at 50, 70, 90 DAT and at harvest, respectively). But in terms of other growth parameters, the highest tillers hill^{-1} 2.87, 9.85, 15.49, 16.98 and 16.27 at 30, 50, 70, 90 DAT and at harvest, respectively and dry weight hill^{-1} 2.52, 30.31, 95.03 and 103.72 g at 30, 60, 90 DAT and at harvest, respectively were achieved by BRRI dhan45 (V_1) where the minimum tillers hill^{-1} (2.24, 7.46, 14.15, 14.53 and 13.88 at 30, 50, 70, 90 DAT and at harvest, respectively) and dry weight hill^{-1} (1.96, 23.33, 86.55 and 92.90 g at 30, 60, 90 DAT and at harvest, respectively) were obtained by

BRRI hybrid dhan3 (V_3). Again, for yield and yield contributing characters viz. The highest panicle length (23.48 cm), number of filled grains panicle^{-1} (100.33), 1000 seed weight (29.33 g), grain yield (8.47 t ha^{-1}), straw yield (9.10 t ha^{-1}), biological yield (17.57 t ha^{-1}) and harvest index (48.20 %) were obtained by BRRI hybrid dhan3 (V_3) where the lowest value of filled grains panicle^{-1} (79.68), grain yield (6.03 t ha^{-1}), straw yield (6.75 t ha^{-1}), biological yield (12.77 t ha^{-1}) and harvest index (47.53%) were obtained by BRRI dhan45 (V_2). But the lowest panicle length (21.69 cm), 1000 seed weight (23.26 g) were observed by BRRI dhan63 (V_2). On the other hand, the maximum effective tillers hill^{-1} (13.98), non-effective tiller hill^{-1} (2.45) and unfilled grains panicle^{-1} (11.34) were achieved by BRRI dhan45 (V_1) where the minimum value effective tillers hill^{-1} (11.90), non-effective tillers hill^{-1} (1.98) and unfilled grains panicle^{-1} (6.84) were BRRI hybrid dhan3 (V_3).

Application of Zinc by different methods significantly increased the crop growth parameters over no Zinc application. The tallest plant (22.91, 47.25, 76.35, 90.61 and 95.46 cm at 30, 50, 70 90 DAT and at harvest, respectively), tillers hill^{-1} (3.10, 9.94, 16.44, 17.26 and 16.41 at 30, 50, 70 90 DAT and at harvest growth stage, respectively) and the highest dry weight hill^{-1} 2.29, 28.56, 105.67 and 119.52 g at 30, 60, 90 DAT and at harvest, respectively ware found from F_3 (soil application). The shortest plant (19.77, 39.49, 68.48, 82.07 and 86.63 cm at 30, 50, 70, 90 DAT and at harvest, respectively), the lowest tillers hill^{-1} (2.41, 7.91, 13.4, 14.60 and 14.07 at 30, 50, 70, 90 DAT and at harvest growth stage, respectively) and the lowest dry weight hill^{-1} (2.08, 24.80, 79.48 and 80.02 g at 30, 60, 90 DAT and at harvest sampling dates, respectively) ware observed by F_0 (no Zn application). The highest effective tillers hill^{-1} (14.49), panicle length (23.69 cm), number of filled grains panicle^{-1} (93.65), 1000 seed weight (27.03 g), grain yield (7.53 t ha^{-1}), straw yield (8.00 t ha^{-1}), biological yield (15.45 t ha^{-1}) and harvest index (48.69 %) were given by F_3 (soil application of Zn) and the lowest effective tiller hill^{-1} (10.91), panicle length (21.73 cm), number of filled grains panicle^{-1} (79.45), 1000 seed weight (24.28 g), grain yield (6.21 t ha^{-1}), straw yield (7.07 t ha^{-1}), biological yield (13.28 t ha-1) and harvest index (46.71 %) were attained by F_0 (no Zn application). But the maximum non-effective tillers hill^{-1} (3.28) and unfilled grains panicle^{-1} (11.03) were achieved in F_0 (no Zn application) where the minimum value non-effective tiller hill^{-1} (1.77) ware obtained from F_1 (root soaking) and unfilled grains panicle^{-1} (7.32) from F_3 (soil application of Zn).

Interaction effect of variety and Zn application methods during the study period had also significant effect on growth, yield and yield contributing parameters. It was noticed that the highest value of plant height was achieved by V_3F_3 (51.37, 80.80, 95.66 and 99.23 cm at 50, 70, 90 DAT and at harvest, respectively) but at very early stage of growth, at 30 DAT, the tallest plant was achieved by V_1F_3 (24.20 cm). The lowest plant (35.33, 63.47, 77.60 and 82.40 cm at 50, 70, 90 DAT and at harvest, respectively) was gained by V_1F_0. But in terms of the highest tillers hill^{-1} (3.67, 11.53, 17.53, 18.80 and 18.03 at 30, 50, 70, 90 DAT and at harvest, respectively) and dry weight hill^{-1} (2.55, 31.67, 108.79 and 128.82 g at all sampling dates, respectively) were attained from V_1F_3 where the lowest tillers hill^{-1} (12.40, 13.27 and 12.93 at 70, 90 DAT and at harvest, respectively) and dry weight hill^{-1} (19.31, 78.13 and 77.09 g at 60, 90 DAT and at harvest, respectively) were obtained from V_3F_0. The highest panicle (24.15 cm), number of filled grains panicle^{-1} (105.51), 1000 seed weight (30.38 g), grain yield (8.90 t ha^{-1}), straw yield (9.31 t ha^{-1}), biological yield (18.21 t ha^{-1}) and harvest index (49.04 %) were achieved by V_3F_3 where the lowest panicle length (20.59 cm), number of filled grains panicle^{-1} (71.19), 1000 seed weight (21.04 g) were obtained from V_3F_3 but the lowest grain yield (5.32 t ha^{-1}), straw yield (6.17 t ha^{-1}), biological yield (1149 t ha^{-1}) and harvest index (46.28 %) were attained by V_1F_0. 0n the other hand, the maximum effective tiller hill^{-1} (16.10) were attained by V_1F_0 and the lowest effective tiller hill^{-1} (10.40) from V_2F_0. The maximum non-effective tiller hill (3.77) were attained by V_1F_0 and the lowest (1.54) was found from V_2F_0. The maximum unfilled grains panicle^{-1} (14.95) were achieved by V_1F_0 the lowest (5.59) was achieved from V_2F_0.

From the above discussion it can be concluded that BRRI hybrid dhan3 demonstrated the best performance on growth, yield and yield contributing characters when Zn was applied with the said dose in soil. Among the interactions V_3F_3 (BRRI hybrid dhan3 × soil application) seems as promosing for higher yield of boro rice varieties. So, considering all, variety BRRI hybrid dhan3, Zn application through soil and their interaction may be adopted for cultivation of boro rice.

Recommendations:

To reach a specific conclusion and recommendations, more research work regarding this issue on boro rice should be done in different agro-ecological zones of Bangladesh with this treatment variable.

REFERENCES

Abid, M., Ahmad, N., Jahangir, M. and Ahmad, I. (2011). Effect of Zinc, Iron and Manganese on growth and yield of Rice (*Oryza sativa* .L). *Pakistan J. Agric Sci.*, **39**(3): 127-132.

Agarwal, H.P. and Gupta, M.L. (1994). Effect of copper and zinc on copper nutrition of rice. *Ann. Agric. Res*., **15**: 162-166.

Ahmed, M. and Elias, S. M. (1986). Socio-economic status of wheat cultivation in Bangladesh, pp. 32-43. BARI-WRC and CIMMYT-CIDA Wheat Program, Dhaka, Bangladesh.

Alam, M. A. and Kumar, M. (2015). Effect of zinc on growth and yield of rice var. Pusa Basmati in Saran district of Bihar. *Asian J. Plant Sci. Res*., **5**(2): 82-85.

Ali, B.A., Salem, A.K.M and Sharkawy, H.M. (2012). Effect of different micronutrient treatments on rice (*Oryza sativa* L.) growth and yield under saline soil conditions. *World J. Agric. Sci.*, **7**(2): 179-184.

Alloway, B.J. (2008). Micronutrient deficiencies in global crop production, springer, Dordrecht, Netherlands, pp.181-200.

Anand, S., Rani, P.P., Pathy, R.L. and Babu, P.R. (20O7). Soil properties and biological activity as influenced by nutrient management in rice- fallow sorghum. *Int. J. Agric. Res. Innov. Tech*., **5**(1): 10-14.

Apoorva, M.R. (2016). Effect of sources and methods of application of zinc on growth, yield and nutrient uptake in rice. Rajendranagar, Hyderabad. pp. 33-34.

BBS (Bangladesh Bureau of Statistics). (2012). Yearbook of Agricultural Statistics of Bangladesh. Bangladesh Bureau of Statistics: Dhaka, Bangladesh, 2012.

BBS (Bangladesh Bureau of Statistics). (2013). Statistical yearbook of Bangladesh. Bangladesh Bur. Stat., Stat. Div., Minis. Plann.Govt. People's Repub. Bangladesh, Dhaka. pp. 123-127.

Barben, S. B., Hopkins, V., Jolley, B. and Nichols, B. (2010).Phosphorus and zinc interactions in chelat or buffered solution grown russet burbank potato. *J. Plant Nutr*. **33**: 587 601.

Bhuiyan, A.M., Baddaruddin, M., Ahmed, N.U. and Razzaque, M.A. (1993). Rice – wheat system research in Bangladesh: a review. Wheat Research Centre, Bangladesh Agricultural Research Institute, Nashipur, Dinajpur, Bangladesh.

Boonchuay, P., Cakmak, I., Rerkasem, B. and Chanakan. (2013). Effect of different foliar zinc application at different growth stages on seed zinc concentration and its impact on seedling vigor in rice. *Soil Sci. Plant Nutr*. **59**: 180–188.

Bremner, J.M. and Mulvaney, R.L. (1978). Urease activity in soils. In: Soil Enzymes (Bums RG, ed.). Academic Press, London. 149-196.

Cakmak, I. (2008). Zinc deficiency in wheat in Turkey. In Micronutrients deficiencies in global crop production, ed. B.J.Alloway. 181-200.New York: Springer.

Channabasavanna, A.S., Yelamali, S.G. and Biradar, D.P. (2001). Response of rice (*Oryza sativa L.*) to sources of organic manures and levels of zinc sulphate in deep black soils. *Indian J. Agron*., **46**(3): 458-461.

Channal, H.T and Kandaswamy, P. (1997). Effect of amendments and zinc levels on the utilisaton of applied zinc by rice in sodic soil. *J. Nuclear Agric. and Biol.* **26**: 15-20.

Chaphale, S.D. and Badole, W.P. (1999). Response of rice (*Oryza sativa*) to zinc application. *Indian J. Agron.* **44**(3): 539-542.

Chaudary, S.K. and Sinha, N.K. (2007). Effect of levels of nitrogen and zinc on grain yield and their uptake in transplanted rice. *J. Plant Nutr.* **44**(1): 44-47.

Deb, D.L. (1986). Zinc and sulphur deficiency (in rice production) in Bangladesh. FAO-UNDP.

Dick, W.A. and Tabatabai, M.A. (1992). Potential uses of soil enzymes. In: Metting FB Jr. (eds.). Soil Microbiology Ecology: Application of Agricultural and Environmental Management, Marcel Dekker, Newyork. 95-127.

Dick, W.A., Cheng, L. and Wang, P. (2000). Soil acid and alkaline phosphatase activity as pH adjustment indicator. *Soil Biol and Biochem*. **32**: 1915-1919.

Dixit, V., Parihar, A.K.S., Kumar, A., Singh, D. and Rahi, T.S. (2012). Effect of Sulphur and Zinc on Yield Quality and Nutrient Uptake of Hybrid Rice in Sodic Soil. *Int. J. Env. Sci. Tech.*, **1**(1): 53-57.

Fageria, N.K. (2004). Dry matter, Yield and Nutrient uptake by Lowland Rice at Different Growth stages. *J. Plant Nutr*. **27**: 947–958.

FAO. Production Year Book. (2011). UN. Rome, Italy. p.118.

Farooq, M. Kobayashi, N.K. and Wahid, A. (2016). Ito O, Basra SMA. Strategies for producing more rice with less water. *Adv Agron*. **101**: 351–388.

Ghoneim, A.M. (2016). Effect of Different Methods of Zn Application on Rice Growth, Yield and Nutrients Dynamics in Plant and Soil Ueno, H. Asagi, N. and Watanabe, *J. Agric. and Ecol. Res*., **43**: 63–69.

Gill, M.S and Singh, V.K. (2009). Productivity enhancement of cereals through secondary and micronutrients application. *Indian J. Fert*., **5**(4): 59-66.

Gomaa, M. A., Radwan, F.I., Kandil, E.E. and Gharib, A.F. (2015). Effect of Nitrogenous Sources and Zinc application Method on Productivity and Quality of Rice (*Oryza sativa* L.). *Middle East J. Applied Sci*., **4**: 913-919.

Goutami, N., Rani, P.P., Pathy, R.L. and Babu, P.R. (2015). Soil properties and biological activity as influenced by nutrient management in rice- fallow sorghum. *Int. J. Agric. Res. Innov. Tech*., **5**(1): 10-14.

Hafeez, B., Khanif, Y.M. and Saleem, M. (2013). Role of Zinc in Plant Nutrition- A Review. *American J. Expt. Agric*., **3** (2): 374-391.

Hernandez, D., Carrion, M., Cabello, R., Rivero, L. and Pema, J.L. (1988). The effect of two sources and two application methods of zinc on irrigated rice. The nia-en-la agricultura, **11**: 111-116.

Hoque, B. and Jahiruddin, M. (1994). Phosphorus and zinc interactions in chelat or buffered solution grown russet burbank potato. *J. Plant Nutr*. **31**: 587 601.

Hoseinzade, A., Yasin, M., Akram, M. and Awan, Z.I. (2014). Response of rice to Zinc application and different N-sources in calcareous soil. *Sci. Vision*., **2**(1): 16-23.

Hossain, M.B., Kumar, T.N. and Ahmed, S. (2001). Effect of zinc, Boron and Molybdenum Application on yield and nutrient uptake by BRRI Dhan 30. *J. Biol. Sci*, **1**(8): 698-700.

Imamul, H. S.M., Islam N.M.and Das, M. (2000). Effect of automobile exhausts on nutritional status of soil and plant. *Bangladesh J Soil Sci*., **26**(1 & 2): 103–111.

Imtaz, M.A.(1995). Microbiological and biochemical properties. In R.W. Weaver, J.S. Angle and P.S. Bottomley (eds.) – Methods of Soil Analysis, Part 2: Soil Enzymes, Soil Science Society of America. Madison. 775 – 833.

Islam, M., Kobayashi, N.K. and Wahid, A. (1986). Ito O, Basra SMA. Strategies for producing more rice with less water. *Adv Agron*. **10**: 351–388.

Jahiruddin, M., Hoque, M.S., Haque, A.K.M. and Roy, P.K. (1992). Influence of boron, copper and molybdenum on grain formation in rice. *Crop Res*., **5**: 35-42.

Jena, P.K. (1999). Zinc management in transplanted rice. M.Sc. (Ag) thesis submitted to Acharya N G Ranga Agricultural University, Hyderabad, India.

Juliano, B.O. (1993). Rice in Human Nutrition. Prepared in Collaboration with FAO, Food and Agriculture Organization of the United Nations, Rome.

Kabeya, M.J. and Shankar, A.G. (2013). Effect of different levels of zinc on growth and uptake ability in rice zinc contrast lines (*Oryza Sativa* L.). *Asian J. Plant Sci. Res.* **3**(3): 112-116.

Kabir, M.M. (1984). Zinc fertility of soil and fertilizer zinc. A lecture note presented for rica production specialist trainees at BRRI 28 July, 1984. BRRI. Joydebpur Gazipur. Pp. 1-3.

Kalyanasundaram, N.K. and Mehta, B. V. (2010). Availability of zinc, phosphorus and calcium in soils treated with varying levels of zinc and phosphate-a soil incubation study. *Plant Soil*., **5**(3): 699-706.

Khanda, N. R., Sinha, R.B., Singh, A.P and Bhogal, N.S. (1997). Rice (*Oryza sativa* L.) response to time and method of zinc application. M.Sc. (Ag) thesis submitted to Acharya N G Ranga Agricultural University, Hyderabad, India.

Keram, K.S., Sharma, B.L. and Sawarkar, S.D. (2012). Impact of Zn application on yield, Quality, Nutrients uptake and Soil fertility in a medium deep black soil (Vertisol*). Int. J. Sci, Environ and Tech*., **1**(5): 563 – 571.

Khan, U.M., Qasim, M. and Khan, I. (2007). Effect of Zn fertilizer on rice grown in different soils of Dera Ismail khan. *Sarhad J. Agric*., **23**(4): 123-129.

Khan, U.M., Qasim, M., Subhan, M., Jamil, M. and Ahmed, R.D. (2003). Response rice to different methods of zinc application in cacarious soil., *Pak. J. appl. sci*., **3**(7): 101-109.

Khuang S., Cak, I., Rerkasem, B. and Chanakan. (2008). Effect of different foliar zinc application at different growth stages on seed zinc concentration and its impact on seedling vigor in rice. *Soil Sci. Plant Nutr*. **52**: 180–188.

Kulandaivel, S., Mishra, B.N and Mishra, P.K. (2003). Direct and residual effect of levels of zinc and iron and their mode of application on productivity of rice-wheat cropping system. *Ann. agric. Res. New Series*., **24**(2): 221-226.

Kulandaivel, S., Mishra, B.N., Gangaiah, B. and Mishra, P.K. (2004). Effect of levels of zinc and iron and their chelation on yield and soil micronutrient status in hybrid rice (*Oryza sativa*) - wheat (*Triticum aestivum*) cropping system. *Indian J. Agron*., **49**(2): 80-83.

Kumar, M., Jha, A.K., Hazarika, S. and Verma, B.C. (2016). Micronutrients (B, Zn, Mo) for Improving Crop Production on Acidic Soils of Northeast India. *The National Academy Sci.*, **39**(2): 85–89.

Kumar, S. and Singh, R. (2006). Integrated nutrient supply system for zinc and sulphur in lowland rice. *Agric. Sci. Dig*., **23**(1): 26-28.

Mali, C.V. and Shaikh, A.R. (1994). Influence of different sources of zinc with and without FYM on yield and nutrient content in rice-gram cropping sequence. *Mysore J. Agric. Sci.*, **27**: 243-251.

Malik, N.J., Chamon, A.S., Mondol, M.N., Elahi, S.F. and Faiz. (2011). Effect of different levels of Zinc on Growth and Yield of Red Amaranth (Amaranthus Sp.) and Rice (*Oryza Sativa*). *J. Bangladesh Ass. Young Res*., **1**: 79-91.

Malla Reddy, M., Padmaja, B., Reddy R.U. and Reddy D.V.V. (2011). Response of low land rice to source, time and method of zinc application. *J. Res.*, **39**(1&2): 14-19.

Manas, D., Arvind k., Ruplal, P., Agarwal, B. K. and Shahil, D.K. (2017). Effect of Zinc Application on Zn Content and Uptake in Grain, Husk and Straw of Hybrid Rice (*Oryza sativa* L.). *Pak. J. appl. sci*., **3**(7): 101-109.

Maqsood, M., M. Irshad, S.A., Wajid and A. Hussain. (2008). Zinc status of rice plant as influenced by different levels and methods of zinc application. *Pak. J. Bio. Sci*., **2**: 1632-1633.

Mascher, R., Sinha, R.B., Singh, A.P and Bhogal, N.S. (1995). Evaluation of methods and time of zinc application to rice. *J. Indian Society of Soil Sci.*, **32**(1): 195-196.

Mehdi, S.M., Ranjha, S.M. and Hussain, T. (1990). Relative efficiency of various sources of zinc.*Sarhad J. Agric*., **6**: 103-106.

Mondal, M.A.R, Jahiruddin, M., Rahman, M. M. and Hashem, M.A. (1992). An investigation on nutrient requermentfor BR11, rice in old Brahmaputra flood Plain Soils. Bangladesh *J. Crop Sci*., **2**:22-31.

Mustafa , G., Ehsanullah, N., Akbar, S.A., Qaisrani, A.,Iqbal, H., Khan, Z., Jabran, K., Chattha, A.A., Trethowan, R., Chattha, T. and Atta, B.M. (2011). Effect of Zinc application on growth and yield of rice (*Oryza sativa* L.). *Int. J. Agro Vet. Med. Sci.,* **5**(6): 530-535.

Muthukumararaja, T.M. and Sriramachandrasekharan, M.V. (2012). Effect of zinc on yield, zinc nutrition and zinc use efficiency of lowland rice. *J. Agric. Tech*., **8**(2): 551-561.

Mythili, S., Natarajan, K and Kalpana, R. (2003). Integrated nutrient supply system for zinc and sulphur in lowland rice. *Agric. Sci. Dig*., **23**(1): 26-28.

Naik, S.K. and Das, D.P. (2007). Effect of split application of zinc on yield of rice (*Oryza sativa* L.) In an inceptisol. *Archives Agron Soil Sci*., **53**(3): 305 – 313.

Neue, M., Jha, A.K., Hazarika, S. and Verma, B.C. (1998). Micronutrients (B, Zn, Mo) for Improving Crop Production on Acidic Soils of Northeast India. *The National Academy Sci.*, **33**(2): 85–89.

Nirmaladevi, P. 2001. Zinc use efficiency in rice hybrids. M.Sc. (Ag) thesis submitted to Acharya N G Ranga Agricultural University, Hyderabad, India.

Prasad, R.K., Kumar, V., Prasad, B. and Singh, A.P. (2010). Long-Term Effect of Crop Residues and Zinc Fertilizer on Crop Yield, Nutrient Uptake and Fertility Build-up under Rice-Wheat Cropping System in Calciorthents. *J. Indian Soc. Soil Sci*., **58**(2): 205-211.

Priyadarsini, J. (2001). Yield and quality of rice as affected by varieties and nitrogen source. M.Sc. (Ag) thesis submitted to Acharya N G Ranga Agricultural University, Hyderabad, India.

Pulla R.C. and Shukla, D.N. (1996). Effect of sources and levels of phosphorus at different levels of zinc on growth and yield of rice. *The Andhra Agric. J*., **43**(1): 30-34.

Pulla Rao, Ch and Shukla, D.N. (1996). Effect of sources and levels of phosphorus at different levels of zinc on growth and yield of rice. *The Andhra Agric. J*., **43**(1): 30-34.

Rahman, A., Yasin, M., Akram, M. and Awan, Z.I. (2002). Response of rice to Zinc application and different N-sources in calcareous soil. *Sci. Vision*., **8**(1): 16-23.

Rahman, M. S.(2001). Effect of tiller plantation on the performance of transplant aman rice. MS Thesis. Dept. of Agronomy, Baangladesh Agricultural University, Mymensingh.

Rahman, M.T., Jahiruddin, M., Humauan, M.R., Alam, M.J. and Khan, A.A. (2008). Effect of sulphur and zinc on growth, yield and nutrient uptake of boro rice (cv. BRRI dhan29). *J. Soil Nat*., **2**(3): 10-15.

Rai, T.N. and Yadav, J. (2011). Influence of inorganic and organic nutrient sources on soil enzyme activities. J. Indian Soc. Soil Sci., 59(1): 54 – 59.

Rajendra P. (2010). Zinc bio-fortification of food grains in relation to food security and alleviation of zinc malnutrition. *Curr. Sci.,* **98**(10): 1300-1304.

Raju, R.A., Reddy, K.A. and Murthy, V.S. (1992). Effect of phosphorus source and levels of zinc on growth and yield of rice (*Oryza sativa*). *Indian J. Agron.*, **37**: 160-162.

Raju, R.A., Reddy, K.A. and Reddy, M.N. (1994). Response of rice (*Oryza sativa*) to sulphur and zinc on coastal alluvials of Andhra Pradesh. *Indian J. Agron*., **39**: 637-638.

Ram, S., Chauhan, R.P.S. and Singh, B.B. (2005). Response of rice (*Oryza sativa*) to zinc application in sodic soil of Uttar Pradesh. *Indian J. Agric. Sci*., **65**(7): 525-527.

Ramalakshmi, C. S. (2011).Vermicomposting for effective waste management and its evaluation under INM rice – pulse cropping system. M.Sc. (Ag.) Thesis. Acharya N. G. Ranga Agricultural University, Rajendranagar, Hyderabad.

Rao, P.C and Raman, S. (1996). Influence of plant cover and stage of crop growth on the activity of soil enzymes. Paper presented in 61st Annual Convention of the Indian Society of Soil Science held at Gujarat Agricultural University, 28th October to 1st Nov.1996.

Rao, R. N. (2003). Rice (*Oryza sativa* L.) response to time and method of zinc application. M.Sc. (Ag) thesis submitted to Acharya N G Ranga Agricultural University, Hyderabad, India.

Ravikiran, S. and Reddy, G.L.N. (2004). Effect of ZnSO4 foliar spray on yield of rice cultivars. *The Andhra Agric J*., **51**(3&4): 438-440.

Reddy, M.G., Murthy, V.S. and Rao, P.G. (1984). Effect of micronutrients on rice. *The Andhra Agric. J.*, **31**(2): 150-153.

Rekabdar, M. F. H. (2004). Dhan Chasher Nana Katha. Krishikatha. **67**(2): 3940.

Sakal, R., Sinha, R.B., Singh, A.P and Bhogal, N.S. (1993). Evaluation of methods and time of zinc application to rice. *J. Indian Society of Soil Sci.,* **41**(1): 195-196.

Sankaran, M.S Mani, S. and Savithri, P. (2001). Effect of teprosyn and zinc sources on yield and nutrient uptake in rice (*Oryza sativa* L.). *Madras Agric J.,* **88** (10-12): 715-716.

Sharma, S.K., Bhunia, S.R. and Pathan, A.R.K. (1999). Effect of zinc fertilization on transplanted rice in Ghaggar flood plains of North-West Rajasthan. *Crop Res*., **20**(2): 245-247.

Shivay, Y.S., Prasad, R., Singh, R.K. and Pal, M. (2015). Relative Efficiency of Zinc-Coated Urea and Soil and Foliar Application of Zinc Sulphate on Yield, Nitrogen, Phosphorus, Potassium, Zinc and Iron Biofortification in Grains and Uptake by Basmati Rice (*Oryza sativa* L.). *J. Agric Sci*., **7**(2): 1916-9752.

Singh, A.K., Manibhushan, Meena, M.K. and Upadhyaya, A. (2012). Effect of Sulphur and Zinc on Rice Performance and Nutrient Dynamics in Plants and Soil of Indo Gangetic Plains. *J. Agric Sci*., **5**(4): 1916-9760.

Singh, M., Srivastava, J.P and Singh, K. (1978). Effect of micronutrients and their methods of application on yield and nutrient uptake of drilled rice variety IR-8. *Indian J. Agron.,* **23(**1): 31-36.

Singh, R. and Sharma, M.P. (1994). Response of rice to different zinc carriers and their methods of application in partially reclaimed salt affected soil. *Fert. News.* **39**(7): 51-52.

Singh, R.P., Yadav, P.K., Singh, R.K., Singh, S.N., Bisen, M.K and Singh, J. (2006). Effect of chemical fertilizer, FYM and biofertilizer on performance of rice and soil properties. *Crop Res*., **32**(3): 283-285.

Sinha, D.N. (2007). Effect of sources and levels of phosphorus at different levels of zinc on growth and yield of rice. *The Andhra Agric. J*., **41**(1): 30-34.

SRDI. (1998). Zinc status of Bangladesh soil. Soil Resource Development Institute, Farmgate, Dhaka, Bangladesh.

Sreenivasa, R. N. (2003). Rice (*Oryza sativa* L.) response to time and method of zinc application. M.Sc. (Ag) thesis submitted to Acharya N G Ranga Agricultural University, Hyderabad, India.

Srilatha, M., Rao, P.C., Sharma, S.H.K. and Bhanu R. K. (2013). Influence of long term fertilizer application on soil phosphatase enzyme activity and nutrient availability in rice-rice cropping system. *J. Rice Res*., **2**: 45-54.

Sriramachandrasekharan, M.V.S. and Mathan, K.K. (2012). Influence of zinc sources on growth characters of rice in low land rice soils. . *Fert. News.* **39**(7): 51-52.. **30**: 256-258.

Stangoulis, J. C. R. and Graham, R. D. (2007). Boron and Plant Disease. In Datnoff, L. E., Elmer, W. H. and Huber, D. M. (Eds.), Mineral Nutr. Plant Disease. USA: The American Phytopath. Society. pp. 207-214.

Tabatabai, M.A.(1994). Microbiological and biochemical properties. In R.W. Weaver, J.S. Angle and P.S. Bottomley (eds.) – Methods of Soil Analysis, Part 2: Soil Enzymes, Soil Science Society of America. Madison. 775 – 833.

Tomar, P.S., Upadhyay, A. and Sharma, J.K. (1994). Effect of zinc on yield and nutritional quality of grain and straw of rice cultures. *Annals of Plant Physiol*. **8**: 66-68.

Trivedi, B.S., Gami, R.C. and Patel, G.G. (1998). Effect of zinc levels on yield and uptake of Zn and Fe by rice varieties and on DTPA-extractable Zn and Fe after rice. *J. Indian Soc. Soil Sci*., **46**(1): 158-159.

Yoshida, S.(1981). Fundamentals of rice crop science. International Rice Research Institute. Los Banos. Philippines. 269.

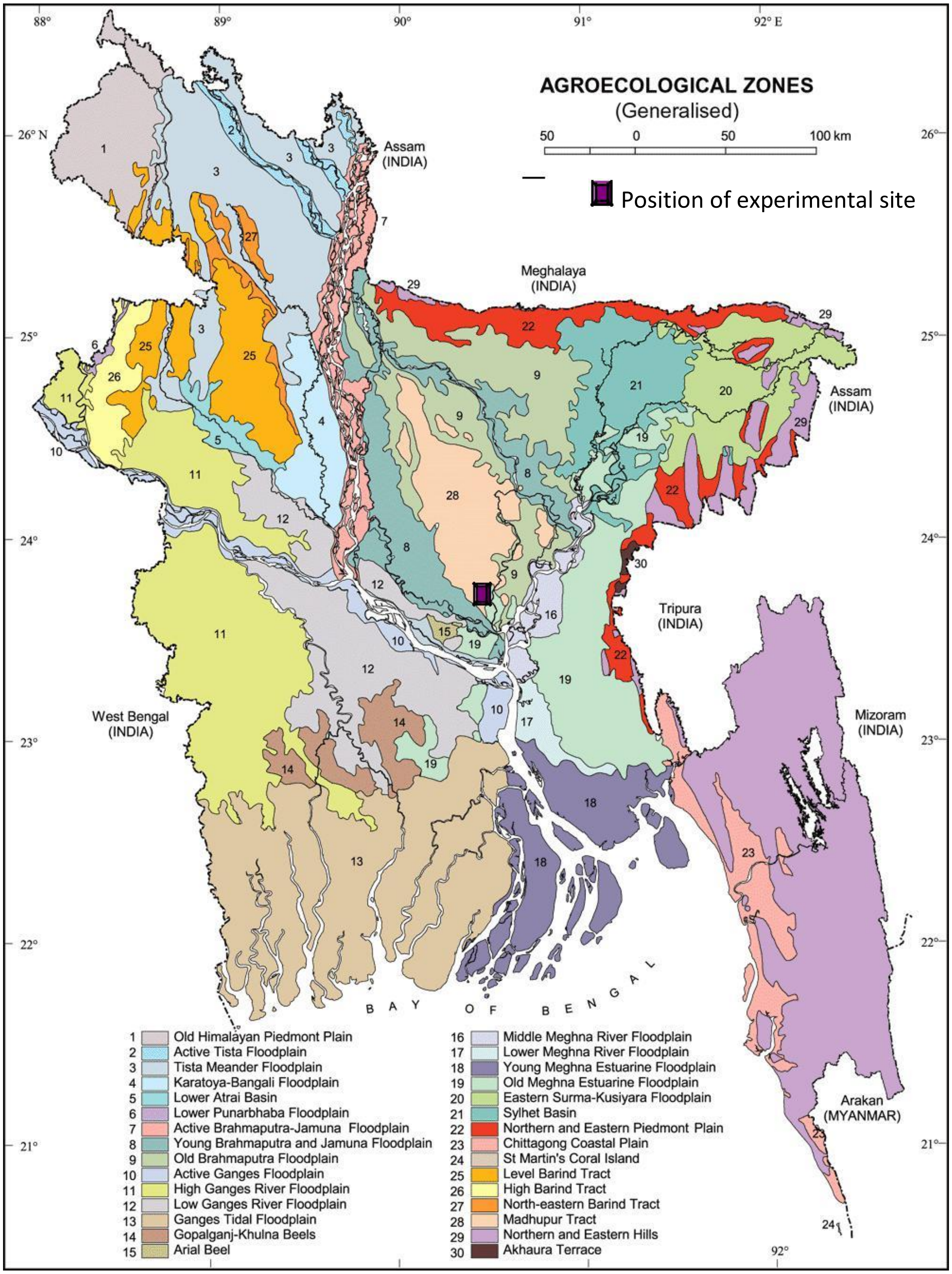
Zayed, B.A., Salem, A.K.M and Sharkawy, H.M. (2011). Effect of different micronutrient treatments on rice (*Oryza sativa* L.) growth and yield under saline soil conditions. *World J. Agric. Sci.,* **7**(2): 179-184.

Zhang, J., Wang, M., Cao, Y., Wu, L. and Xu, S. (2012). Iron and Zinc accumulation trend in a Japonica rice grains after anthesis. *African J. Agric. Res.*, **7**(8): 1312-1316.

Zhao, F.J. and Mcgrath, S.P.(2009). Biofortification and phytoremediation. *Curr. Opin. Plant Biol.,* **12**(3): 373–380.

APPENDICES

Appendix I. Map showing the experimental sites under study



Appendix II. Monthly records of air temperature, relative humidity and rainfall during the period from November 2017 to April 2018.

Month	RH (%)	Air temperature (C)			Rainfall (mm)
		Max.	Min.	Mean	
November	65	32.0	19.0	26.0	35
December	74	29	15	22	15
January	68	26	10	18	7
February	57	15	24	25.42	25
March	57	34	16	28	65
April	66	35	20	28	155

(Source: timeanddate.com)

Appendix III. Morphophysiological and chemical characteristics of experimental soil

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Agronomy Farm, SAU, Dhaka
AEZ	Modhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping pattern	Not Applicable

Source: Soil Resource Development Institute (SRDI), Farmgate, Dhaka.

B. Physical and chemical properties of the initial soil

Characteristics	Value
Partical size analysis % Sand	27
%Silt	43
% Clay	30
Textural class	Silty Clay Loam (ISSS)
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20
Exchangeable K (me/100 g soil)	0.1
Available S (ppm)	45

Source: Soil Resource Development Institute (SRDI), Farmgate, Dhaka.

Appendix IV. Calendar of operations

Field operation	Date
Initial soil sample collection from main field	20-11-2017
Preparation of nursery bed	22-11-2017
Sowing of sprouted seeds in nursery	23-11-2017
Puddling of main field	27-12-2017
Layout of main field	01-01-2018
Basal treatment application (Urea, TSP, MoP, and $ZnSO_4H_2O$ as soil application treatment)	01-01-2018
Root soaking treatment application (1.50%$ZnSO_4H_2O$ solution prior transplanting)	02-01-2018
Transplanting	02-01-2018
Foliar treatment application at 20 DAT (2 % $ZnSO_4H_2O$ solution)	22-01-2018
Biometric observation at 30 DAT	02-02-2018
Insecticide application carbofuran 3G@1kg a.i ha^{-1}	06-02-2018
Biometric observation at 50 DAT	22-02-2018
Biometric observation at 70 DAT	14-03-2018
Biometric observation at 90 DAT	04-04-2018
Biometric observation at harvest	28-05-2018
Net plot harvesting and threshing	29-05-2018
Harvesting of the bulk crop and threshing	30-05-2018
Drying of grain and straw plot wise	31-05-2018
Dry weight of straw and grain plot wise	04-06-2018