# EFFECT OF DIFFERENT SCHEDULING OF NITROGEN AND ZINC APPLICATION ON HYBRID RICE

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# EFFECT OF DIFFERENT SCHEDULING OF NITROGEN AND ZINC APPLICATION ON HYBRID RICE

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## *CERTIFICATE*

*This is to certify that thesis entitled, "**EFFECT OF DIFFERENT SCHEDULING OF NITROGEN AND ZINC APPLICATION ON HYBRID RICE**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) in AGRICULTURAL BOTANY** embodies the result of a piece of bona-fide research work carried out by **ANANYA SHARMA**, Registration no. **14-05882** 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.*

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# EFFECT OF DIFFERENT SCHEDULING OF NITROGEN AND ZINC APPLICATION ON HYBRID RICE

## ABSTRACT

The field experiment was conducted at the Experimental plot of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 during the period from November, 2019 to May, 2020 in *Boro* season to find out the effect of nitrogen and zinc scheduling on performance of hybrid rice. BRRI hybrid dhan2 was used as planting material in this study. The experiment consisted of two factors: Factor A: Nitrogen management (3 levels) as i) $N_0$ – 0 kg ha$^{-1}$ (control), ii) $N_1$ – 100 kg ha$^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and iii) $N_2$ – 150 kg ha$^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]. Factor B: Zinc management (4 levels) as i) $Zn_0$ - 0 kg ha$^{-1}$ (control), ii) $Zn_1$ – 5 kg ha$^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], iii) $Zn_2$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and iv) $Zn_3$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]. The experiment was laid out in a Randomized Complete Block Design (Factorial) with three replications. Data on different growth and yield parameters of rice were recorded and significant variation was observed for different treatments. The maximum number of panicles hill$^{-1}$ (14.25), the longest panicle (25.73 cm), the highest number of grains panicle$^{-1}$ (111.95), the maximum 1000-grain weight (25.50 g), the highest grain yield (7.11 t ha$^{-1}$), the maximum straw yield (7.40 t ha$^{-1}$), significantly the maximum biological yield of 14.51 t ha$^{-1}$ and the highest value of harvest index (48.33%) were found from $N_2$ (150 kg N ha$^{-1}$) treatment. The highest number of panicles hill$^{-1}$ (13.33), the highest value of grains panicle$^{-1}$ (106.11), the maximum weight of 1000-grains (24.38 g), the highest grain yield (6.32 t ha$^{-1}$), the maximum straw yield (6.86 t ha$^{-1}$), the maximum biological yield (13.18 t ha$^{-1}$) and the highest value of harvest index (47.20%) was found from $Zn_2$ (10 kg Zn ha$^{-1}$) treatment. The application of 150 kg N ha$^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT] and 10 kg Zn ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] provided significantly higher yield contributing and yield parameters in BRRI hybrid dhan2.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AEZ | Agro-Ecological Zone |
| BBS | Bangladesh Bureau of Statistics |
| CV % | Percent Coefficient of Variance |
| *cv*. | Cultivar (s) |
| DAT | Days After Transplanting |
| eds. | editors |
| *et al.* | et alia (and others) |
| etc. | et cetera (and other similar things) |
| FAO | Food and Agricultural Organization |
| L. | Linnaeus |
| LSD | Least Significant Difference |
| *i.e*. | id est (that is) |
| MoP | Muriate of Potash |
| SAU | Sher-e-Bangla Agricultural University |
| SRDI | Soil Resources and Development Institute |
| TSP | Triple Super Phosphate |
| UNDP | United Nations Development Programme |
| USP | Urea Super Granule |
| *var*. | variety |
| *viz*. | namely |

# CHAPTER I

# INTRODUCTION

Rice (*Oryza sativa* L.) belongs to the family 'Poaceae', is the most important cereal crop in tropical and subtropical regions (Singh *et al*., 2012). It is the primary food for more than 65% of the world's population (FAO, 2014) and is grown in more than a hundred of countries across the world (Jahan *et al.*, 2017). Rice grain contains 80% carbohydrate, 7.10% protein, 0.66% fat, 0.12% sugar, 1.30% dietary fibre and sufficient amount of minerals for human diet. It is rich in potassium (115 mg 100 $g^{-1}$), phosphorus (115 mg 100 $g^{-1}$), magnesium (25 mg 100 $g^{-1}$), calcium (28 mg 100 $g^{-1}$), iron (4.31 mg 100 $g^{-1}$), and other minerals (USDA, 2012). A total of 474.86 million metric tons was produced from 159.64 million hectares of land in 2014–15 (USDA, 2015). Rice provides for 21% of the calorific intake of the world and 76% of the calorific intake of the total population of south-east Asian region countries (Fitzgerald *et al*., 2009). Above 90% of total produced rice is consumed in Asia (FAO, 2014). Rice grain has shaped the culture and economy of billions of world people (Farooq *et al.,* 2009).

Bangladesh ranks $4^{th}$ in both area and production and $6^{th}$ in per hectare production of rice (Sarkar *et al*., 2016). In Bangladesh, rice covers an area of about 11,420,725 ha and total production is about 34,710,417 metric tons (BBS, 2015). According to FAO (2014) the average yield of rice of Bangladesh is about 2.92 t $ha^{-1}$ which is very low compared to other rice growing countries like Korea (6.30 t $ha^{-1}$), China (6.30 t $ha^{-1}$) and Japan (6.60 t $ha^{-1}$).

Bangladesh is an over populated country. Rice occupies its 77% of the total cropped area, contributes about 70 to 80 % of total food grain production and continues to play a vital role in the national food and livelihood security system (Haque *et al.*, 2018). About two million of people are being added every year which will be 30 million over the next 20 years and thus, to meet up the food supply for this over population, Bangladesh needs 37.26 million tons of rice for the year 2020 (BRRI, 2011). Population growth in Bangladesh demand a continuous increase of rice production and the highest priority has been given for this (Bhuiyan, 2004). World food security become challenged for increasing food demand and estimated that about 114 million tonnes of additional rice will be needed by 2035 which is equivalent to overall increase of 26% for next 25 years (Kumar and Ladha, 2011). Rice production has to be increased at least 60% by 2020 to meet up food requirement of the increasing population (Masum, 2009). Thus, the population by the year 2030 will swell progressively to 223 million which will demand additional 48 million tons of food grains (Julfiquar *et al*., 2008).

In recent years there is an increasing preference among consumers for foods that content not only traditional nutrients but also provide other compounds particularly micronutrient that are beneficial to health and well-being. Among micronutrients, zinc deficiency affects one third of the world's population (Zhang *et al.*, 2012). Zinc is essential for all humans, animals and plants (Zou *et al.*, 2012). It is vital for the proper functioning of the immune system and crucial for healthy growth, physical and mental development of children. Cereal crops play an important role in satisfying daily calorie intake in developing world, but they are inherently very low in Zn concentrations in grain (Cakmak, 2008 and Cakmak *et al.*, 2010), particularly when grown on Zn-deficient soils. The reliance on cereal-based diets may induce Zn deficiency-related health problems in humans, such as impairments in physical development, immune system and brain function a hidden hunger or malnutrition. In Bangladesh 26% population are suffering from zinc deficiency (Bouis *et al.*, 2010). For effective zinc nutrition one person requires 15 mg Zn day$^{-1}$ but our food grains contain only 15–35 mg Zn kg$^{-1}$ (Cakmak, 2012) and out of which only 13–35% are bio available. So, there is a big gap between daily requirement- daily intake and to fulfil the gap our food grains should contain 40–60 mg Zn kg$^{-1}$ (Wei *et al.*, 2012).

The soil and foliar Zn application greatly contributes to maintenance of adequate root Zn uptake (by soil application) and transport Zn from leaf tissue (by foliar application) to the seeds during reproductive growth stage (Cakmak, 2012).

Nitrogen stimulates root growth and crop development as well as uptake of the other nutrients. Nitrogen is an essential element in determining rice grain yield and N fertilizer is one of the major inputs to paddy fields which have favourable effect of promoting tillering and increasing spikelet number per panicle (Jan *et al.*, 2013). Rice is very sensitive to insufficient nitrogen and very responsive to nitrogen fertilization (Dubey *et al.*, 2016). N uptake by rice is very slow during early growth stages. Hence, fertilizer N application at high doses during these stages could be prone to losses (Ali *et al.*, 2009).

After nitrogen, zinc is the second most yield limiting nutrient in rice. The response of rice crop to nitrogen fertilizers have been well documented, however the effects of N interaction with zinc application rates on yield and quality of rice are lacking. Non-judicious use of nitrogen fertilizer could further aggravate Zn deficiency in alkaline soils and suppress paddy growth and yield.

Growth stage is an important implement for agronomic decision for timely application of fertilizer for better crop growth and development. Zadoks scale is much more descriptive of various stages of development and 100 individual growth stages.

Zadoks growth scale developed by Dutch renowned researcher Jan C. Zadoksis recognized internationally and widely used in cereal research and farm practice, particularly to know the critical time for application of chemicals and fertilizers. Rice growing countries India, Pakistan, Thailand, Vietnam, Myanmar and China have been extensively used this scale in research for improving their rice yield and qualities. But in our country its use is completely absent.

Above mentioned fact clearly indicates the appropriate time of nutrient application increase the yield of rice crop. Hence, keeping in view, the importance of nitrogen and zinc for yield in rice, the present investigation was designed and carried out.

## Objectives

The present research project was chalked out to achieve the following objectives-

1. To evaluate the growth, yield and yield attributes of hybrid rice under nitrogen and zinc management,
2. To assess the combined effect of nitrogen and zinc on hybrid rice.

# CHAPTER II

# REVIEW OF LITERATURE

Nitrogen is a major component of proteins, chlorophyll, hormones, vitamins and enzymes, which is vital for rice. Rice plants require a large amount of nitrogen at the early and mid-tillering stage to maximize the number of panicles (De Datta, 1988). The recommended doses of other nutrients like zinc are also necessary for potential rice yield. Considering the above point, available literatures were reviewed under nitrogen and zinc application for hybrid rice.

## 2.1 Effect of Nitrogen on rice

Adhikari *et al.* (2018) conducted the research work during Aman season to study the effect of nitrogen fertilizer and weed management on the growth and yield of transplant Aman rice cv. BRRI dhan46. The experiment consisted of four fertilizer treatments viz. 0 kg N ha$^{-1}$ ($N_0$), 40 kg N ha$^{-1}$ ($N_1$), 80 kg N ha$^{-1}$ ($N_2$) and 120 kg N ha$^{-1}$ ($N_3$) and five weeding treatments viz. one hand weeding at 20 DAT ($W_1$), two hand weedings at 20 and 35 DAT ($W_2$), three hand weedings at 20, 35 and 50 DAT ($W_3$), weeding by Japanese rice weeder twice at 20 and 35 DAT ($W_4$) and unweeded control ($W_5$). The tallest plant (113.00 cm), number of total tillers hill$^{-1}$ (8.74), number of effective tillers hill$^{-1}$ (6.18), panicle length (21.98 cm), grain number panicle$^{-1}$ (114.20), grain yield (4.00 t ha$^{-1}$), straw yield (5.25 t ha$^{-1}$) and biological yield (9.25 t ha$^{-1}$) were recorded in $N_2$ (80 kg N ha$^{-1}$) treatment. The shortest plant (106.00 cm), number of total tillers hill$^{-1}$ (7.20), number of effective tillers hill$^{-1}$ (5.00), panicle length (20.70 cm), grain number panicle$^{-1}$ (97.60), grain yield (3.52 t ha$^{-1}$), straw yield (4.46 t ha$^{-1}$) and biological yield (7.97 t ha$^{-1}$) were recorded from $N_0$ (No nitrogen fertilizer control) treatment.

Pramanik *et al.* (2015) conducted a field experiment during Kharif season of 2010 and 2011 to investigate the optimization of nitrogen levels under different phytohormones application on growth and yield of hybrid rice. Eight treatment combinations were applied consisted of four levels of nitrogen viz. $N_0$, $N_{50}$, $N_{100}$ and $N_{150}$ kg $ha^{-1}$ and two levels of phytohormones viz. brassinosteroids and salicylic acid. Among of the nitrogen levels $N_{150}$ kg $ha^{-1}$ and brassinosteroids gave significant higher plant height, effective tillers $hill^{-1}$, panicle length, filled grains $panicle^{-1}$, total grains $panicle^{-1}$, test weight, fertility%, sterility%, grain yield, straw yield, biological yield and harvest index as compared to $N_0$, $N_{50}$, $N_{100}$ during both years. $N_{150}$ kg $ha^{-1}$ produced significantly the highest grain yield of 69.13 and 71.03 kg $ha^{-1}$ in 2010 and 2011, respectively. The percentage of two years mean grain yields an increase of 53.33%, 28.19% and 11.17% over $N_0$, $N_{50}$, $N_{100}$, respectively.

Pramanik and Bera (2013) conducted a field experiment during Kharif season of 2010 and 2011 to investigate the optimization of nitrogen levels under different age of seedlings transplanted on growth, chlorophyll content, yield and economics of hybrid rice. Fifteen treatment combinations consisted of five levels of nitrogen viz. $N_0$, $N_{50}$, $N_{100}$, $N_{150}$ and $N_{200}$ kg $ha^{-1}$ and three levels of seedlings age (10, 20 and 30 days). Among of the nitrogen levels $N_{200}$ kg $ha^{-1}$ gave significantly higher Plant height, panicle initiation, Number of tillers $hill^{-1}$, total chlorophyll content, panicle length and straw yield and nitrogen levels $N_{150}$ kg $ha^{-1}$ gave significantly higher Number of effective $tillers^{-1}$, effective tiller index, panicle weight, filled grain $panicle^{-1}$, 1000 grain weight, grain yield, and harvest index as compared to $N_0$, $N_{50}$, $N_{100}$ during both years. $N_{150}$ kg $ha^{-1}$ produced significantly the highest grain yield of 6286 and 6652 kg $ha^{-1}$ in 2010 and 2011, respectively. The percentage of grain yields an increase of 72.5%, 44.4%, 23.8% and 5.1% in first year and 69.9%, 44.1%, 22.1% and 3.5% in second year over $N_0$, $N_{50}$, $N_{100}$ and $N_{200}$ kg $ha^{-1}$ respectively.

Qurashi *et al.* (2013) carried out an experiment to evaluate the effect of urea super granule (USG) as a source of nitrogen on the yield and yield components of transplant Aman rice cv. BRRI dhan39, BRRI dhan46 and BINA dhan7. Five levels of N (viz., 0, 60, 120 kg $ha^{-1}$ as prilled urea and 60 and 120 kg $ha^{-1}$ as

USG) were taken as experimental treatments. All the yield and yield components except 1000-grain weight were influenced significantly by the levels of nitrogen fertilizer. The highest grain yield (4.82 t $ha^{-1}$) was recorded in BINA dhan7 and the lowest one (4.30 t $ha^{-1}$) was recorded in BRRI dhan39. Nitrogen @ 120 kg $ha^{-1}$ as USG performed the best among the treatments in respect of yield and yield components of rice. The highest grain yield (5.46t $ha^{-1}$) was obtained from BINA dhan7 with 120 kg N $ha^{-1}$ as USG which was statistically identical with 60 kg N $ha^{-1}$ as USG. A considerable amount (31.25%) of prilled urea (PU) nitrogen could be saved by using USG.

Alim (2012) conducted the experiment to study the effect of different sources and doses of nitrogen application on the yield formation of Boro rice. The experiment consisted of two modern rice varieties (BRRI dhan28 and BRRI dhan36) and 21 fertilizer combinations viz., $T_1$ (control), $T_2$ (60 kg N $ha^{-1}$ as urea), $T_3$ (60 kg N $ha^{-1}$ as cow dung), $T_4$ {60 kg N $ha^{-1}$ as mustard oil cake (MOC)}, $T_5$ (30 kg N $ha^{-1}$ as urea + 30 kg N $ha^{-1}$ as cow dung), $T_6$ (30 kg N $ha^{-1}$ as urea + 30 kg N $ha^{-1}$ as MOC), $T_7$ (80 kg N $ha^{-1}$ as urea), $T_8$ (80 kg N $ha^{-1}$ as cow dung), $T_9$ (80 kg N $ha^{-1}$ as MOC), $T_{10}$ (40 kg N $ha^{-1}$ as urea + 40 kg N $ha^{-1}$ as cow dung), $T_{11}$ (40 kg N $ha^{-1}$ as urea + 40 kg N $ha^{-1}$ as MOC), $T_{12}$ (100 kg N $ha^{-1}$ as urea), $T_{13}$ (100 kg N $ha^{-1}$ as cow dung), $T_{14}$ (100 kg N $ha^{-1}$ as MOC), $T_{15}$ (50 kg N $ha^{-1}$ as urea + 50 kg N $ha^{-1}$ as cow dung), $T_{16}$ (50 kg N $ha^{-1}$ as urea + 50 kg N $ha^{-1}$ as MOC), $T_{17}$ (120 kg N $ha^{-1}$ as urea), $T_{18}$ (120 kg N $ha^{-1}$ as cow dung), $T_{19}$ (120 kg N $ha^{-1}$ as MOC), $T_{20}$ (60 kg N $ha^{-1}$ as urea + 60 kg N $ha^{-1}$ as cow dung) and $T_{21}$ (60 kg N $ha^{-1}$ as urea + 60 kg N $ha^{-1}$ as MOC). Grain and straw yields were increased with the increase of nitrogen rate up to 120 kg $ha^{-1}$ at all the sources. The application of 60 kg N $ha^{-1}$ as urea with 60 kg N $ha^{-1}$ as mustard oil cake (MOC) produced maximum grain and straw yield which was statistically similar to the yield of 50 kg N $ha^{-1}$ as urea with 50 kg N $ha^{-1}$ as MOC. The lowest values were found in control nitrogen application. The results suggest that replacement of 50% urea N by MOC was the best source of nitrogen considering higher yield of Boro rice. Therefore, fertilization of BRRI dhan28 and BRRI dhan36 varieties of rice with 60 kg N ha$^{-1}$ as urea and 60 kg N ha$^{-1}$ as MOC or 50 kg N ha$^{-1}$ as urea with 50 kg N ha$^{-1}$ as MOC was found to be the best nitrogen rate among all the treatment combinations in respect of grain and straw yields.

Naher (2011) conducted a research work with a view to finding out a comparative study on effect of seed source and nitrogen on the yield of hybrid rice. The experiment consisted of the following treatments (a) five varieties viz.; $V_1$ = Heera dhan (Local); $V_2$ = Heera dhan (Overseas); $V_3$ = ACI-1 (Local); $V_4$ = ACI-1 (Overseas); $V_5$ = BRRI dhan29 and (b) three of levels of nitrogen viz., no nitrogen (Control), 80 kg N ha$^{-1}$ and 120 kg N ha$^{-1}$. Fertilizer level differed significantly in all growth characters and yield attributes except panicle length and 1000-grain weight (g). The highest grain yield (5.67 t ha$^{-1}$) was obtained with 120 kg urea application and the lowest yield (4.89 t ha$^{-1}$) was recorded in the control treatment.

Hasanuzzaman (2010) carried out the Experiment to study the influence of levels of nitrogen and phosphorus on the growth and yield of hybrid rice Heera1. There were six nitrogen fertilizer levels *viz.*, $N_0$ = no nitrogen, $N_1$ = 80 kg N ha$^{-1}$, $N_2$ = urea super granules (2.7 g) @ 75 kg N ha$^{-1}$), $N_3$ = 120 kg N ha$^{-1}$, $N_4$ = 160 kg N ha$^{-1}$, $N_5$ = 200 kg N ha$^{-1}$ and four phosphorus fertilizer levels *viz.*, $P_0$ = no phosphorus, $P_1$ = 30 kg $P_2O_5$ ha$^{-1}$, $P_2$ = 50 kg $P_2O_5$ ha$^{-1}$ and $P_3$ = 70 kg $P_2O_5$ ha$^{-1}$. Urea was top dressed in three equal splits at 10, 35 and 55 DAT. The USG (2.7 g) was placed at 5–10 cm soil depth at 10 DAT in the centre of four hills in alternate rows @ 1 granule in one spot to supply 75 kg N ha$^{-1}$. Results indicated that the effect of nitrogen showed significant variation in respect of all growth, yield contributing characters and yield. At harvest, the tallest plant (96.74 cm), maximum tillers hill$^{-1}$ (14.22), LAI (7.72), total dry matter (66.26 g), effective tillers hill$^{-1}$ (13.63), panicle length (24.29 cm), filled grains panicle$^{-1}$ (154.67), total grains panicle$^{-1}$ (159.20), 1000-grains weight (29.35 g), grain yield (9.42 t ha$^{-1}$), straw yield (13.33 t ha$^{-1}$) and biological yield (22.75 t ha$^{-1}$) was obtained from the application of USG. About 10% more grain yield was measured from USG than PU.

Hossain *et al.* (2008) conducted a field experiment to evaluate the effect of different nitrogen levels on the performance of four rice varieties in transplanted Aman (monsoon) season. Aromatic rice varieties included BRRI dhan38, Kalizira, Badshabhog and Tulshimala, while nitrogen was applied at 30, 60, 90 and 120 kg $ha^{-1}$. Different nitrogen rates significantly affected the aromatic rice varieties. All the yield components were significantly increased up to 90 kg N $ha^{-1}$. Nonetheless, maximum grain yield (3.62 t $ha^{-1}$) was observed from 60 kg N $ha^{-1}$.

Islam (2004) carried out an experiment in pots to assess the effect of four nitrogen levels viz. $T_1$ (full doze of urea i.e. 215 kg urea $ha^{-1}$ at one split, at 15 DAT), $T_2$ (full doze of urea at two equal splits, ½ at 15 DAT + ½ at 30 DAT), $T_3$ (full doze of urea at two equal splits, ½ at 15 DAT + ½ at 55 DAT) and $T_4$ (full doze of urea at three equal splits, ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at 55 DAT) on growth, yield and yield attributes of Boro rice genotypes viz. $V_1$ (Binadhan5), $V_2$ (Tainan3) and $V_3$ (Binadhan6). Plant height, number of tillers $hill^{-1}$, number of leaves $hill^{-1}$, leaf area $hill^{-1}$ ($cm^2$), DM (dry matter) of root, stem and leaves $hill^{-1}$, TDM (total dry matter) $hill^{-1}$, chlorophyll content in leaves (at 74 DAT), number of panicle $hill^{-1}$, length of panicle, number of filled grain $panicle^{-1}$, 1000-grain weight, grain yield $hill^{-1}$, biological yield $hill^{-1}$ and harvest index were increased over the $T_1$. All the above parameters showed the highest values when the plants were treated with $T_4$ and the lowest in $T_1$. Among the treatments, $T_4$ showed the best performance. Full dose of urea (215 kg urea $ha^{-1}$) applied at three equal splits at 15, 30 and 55 DAT were found to be the most beneficial one for the rice genotypes.

## 2.2 Effect of nitrogen on plant growth characters

### 2.2.1 Number of tillers hill$^{-1}$

BRRI (2008a) conducted an experiment to study the comparative study of some promising lines with BRRI modern rice varieties to different nitrogen levels *viz*. 0, 30, 60, 90, 120 and 150 kg N ha$^{-1}$. It was reported that tiller production of rice plant with N @ 120 kg ha$^{-1}$ produced significantly higher tiller than those of lower N levels.

BRRI (2006) reported that the maximum tillers hill$^{-1}$ (10.2) was produced with 120 kg N ha$^{-1}$ compared to 90 and 0 kg N ha$^{-1}$ application in rice field.

Lang *et al*. (2003) conducted a field experiment to study the effect of different fertilizer application rates on seedling of Jinyou 207, Guihuanian and Teyou 524 which were sown in no-tillage plots situated in 3 different counties in Guangxi, China. At an early stage of growth, the seedlings were subjected to one of three nitrogen fertilizer treatments: Treatment A used a conventional application rate (CAR) of 157-5-172.5 kg ha$^{-1}$N, treatments B and C used CAR + 10% and CAR + 20%, respectively. They found that the increase in nitrogen fertilizer application rate increased the speed of seedling establishment and tillering peak.

Wang *et al*. (2002) reported that the tiller number increased with increasing nitrogen levels in rice field.

Kumar and Subbaiah (2001) noted that application of DAP + urea resulted in the highest number of tillers m$^{-2}$ in rice plants.

Rajendran and Veeraputhiran (1999) observed that productive tillers m$^{-2}$ increased as the N rate increased in rice field.

Maske *et al*. (1997) concluded that plant height, leaf area hill$^{-1}$, number of tillers hill$^{-1}$ dry matter hill$^{-1}$ and grain yield increased significantly with increased N level.

Idris and Matin (1990) observed that maximum number of tillers hill$^{-1}$ was produced with 140 kg N ha$^{-1}$ which was identical with 60, 80, 100 and 120 kg N ha$^{-1}$. The minimum tillers hill$^{-1}$ was obtained from the control treatment (0 kg N ha$^{-1}$).

### 2.2.2 Leaf area index (LAI)

Masum *et al*. (2008) conducted an experiment to study the effect of four levels of seedling hill$^{-1}$ *viz*; 1, 2, 3 and 4 and two forms of nitrogen i.e. prilled urea (PU) and urea super granules (USG) on yield and yield components of modern (BRRI dhan44) and traditional (Nizershail) transplant Aman rice. They reported that leaf area index was significantly higher in USG receiving plants than plants receiving prilled urea.

Hamidullah *et al*. (2006) conducted an experiment to observe the growth and yield performance of BINA dhan 5 in Boro season as affected by nitrogen levels *viz*. 80, 120 and 160 kg N ha$^{-1}$. They reported that leaf area index was peak at 60 DAT and declined thereafter, highest 5.53 obtained with 160 kg N ha$^{-1}$ at 60 DAT.

Miah *et al.* (2004) found that LAI was significantly higher in USG receiving plots than urea receiving plots at heading stage of rice plants.

Tang *et al*. (2003) conducted a field test with the super hybrid rice (SHR) combination Liangyoupeijiu in Changsha, Hunan, China. Nine treatments were used, including 0, 60, 120, 180, 240, 180, 130, 225 and 160 kg N ha$^{-1}$. They reported that higher amount of N fertilizer application ensured a higher leaf area index.

### 2.2.3 Crop growth rate (CGR)

Das and Panda (2004) conducted a field experiment in Bhubaneswar, Orissa, India, to study the effects of N (0, 60, 120 or 180 kg $ha^{-1}$) and K (0, 40, 80 or 120 kg $ha^{-1}$) on the growth rate of hybrid rice 6102. N (urea) was applied as a basal dressing (25%), and as a top dressing at 18 days after transplanting (DAT) (50%) and at the panicle initiation stage (25%). Irrespective of treatment difference, Crop growth rate (CGR) was greater at 40–60 DAT and lower at 20–40 DAT. The increase in the N rate increased CGR.

## 2.3 Effect of nitrogen on yield contributing character

## 2.3.1 Effective tillers $hill^{-1}$

Awan *et al*. (2011) conducted an experiment to study the effect of different nitrogen levels (110, 133 and 156 kg N $ha^{-1}$) in combination with different row spacing (15 cm, 22.5 cm and 30 cm). They noted that maximum level of N (156 kg N $ha^{-1}$) produced maximum effective tillers irrespective of spacing.

Singh and Shivay (2003) conducted a field experiment to study the effect of coating prilled urea with eco-friendly neem formulations in improving the efficiency of nitrogen use in hybrid rice. Two rice cultivars, hybrid rice (NDHR-3) and Pusa Basmati-1, formed the main plots, with the levels of nitrogen (0, 60, 120 and 180 kg N $ha^{-1}$) and various forms of urea at 120 kg N $ha^{-1}$in the subplots. They found that increasing levels of nitrogen significantly increased the number of effective tillers $hill^{-1}$.

Meena *et al*. (2002) studied the response of hybrid rice to nitrogen (0, 100 and 200 kg $ha^{-1}$) and potassium application (0, 75 and 150 kg $ha^{-1}$). They observed that application of nitrogen significantly increased the effective tillers.

Jee and Mahapatra (1989) observed that number of effective tillers $m^{-2}$ in rice field were significantly higher with 90 kg N $ha^{-1}$ as deep placed USG than split application of urea.

Rama *et al.* (1989) mentioned that effective tiller increased significantly in rice plants when nitrogen level increased from 40 to 120 kg N $ha^{-1}$ as different modified urea materials and USG produced significantly higher effective tiller than split application of PU.

### 2.3.2 Panicle length

Hasanuzzaman *et al*. (2009) conducted an experiment to study the economic and effective method of urea application in rice crop. They noted that urea super granules produced longest panicle (22.3 cm).

Islam *et al*. (2008a) conducted an experiment to study the effect of nitrogen and number of seedlings per hill on the yield and yield components of T. Aman rice (BRRI dhan 33). They noted that panicle length and number of grain $panicle^{-1}$ increased with the application rate of N up to 100 kg $ha^{-1}$ and then declined with further increase in N fertilizer application.

Singh and Shivay (2003) found that increasing levels of nitrogen fertilizer significantly increased the panicle length of rice plants.

Meena *et al*. (2002) observed that increase in nitrogen fertilizer application rate enhanced length and weight of panicles of hybrid rice.

Singh and Singh (1993) observed that panicle $m^{-2}$, panicle length and grains $panicle^{-1}$ increased due to application of 60 kg N $ha^{-1}$.

Idris and Matin (1990) conducted an experiment to study the response of four exotic strains of Aman rice to urea. They concluded that the rate of nitrogen application influenced panicle length positively.

Sen and Pandey (1990) carried out a field trial to study the effects of placement of USG (5, 10 or 15 cm deep) or broadcast PU @ 38.32 kg N $ha^{-1}$ on rice. They revealed that all depths of USG placement resulted in higher yield characters than broadcast PU; however, differences except for panicle lengths were not significant.

### 2.3.3 Filled grains $panicle^{-1}$ and unfilled grains $panicle^{-1}$

Masum *et al*. (2010) reported that placement of N fertilizer in the form of USG @ 58 kg N $ha^{-1}$ produced the highest number of effective tillers $hill^{-1}$, filled grains $panicle^{-1}$ in rice plants which ultimately gave the higher grain yield than split application of urea.

Edwin and Krishnarajan (2005) conducted a field experiment to study the effects of irrigation and N fertilizer treatments on the yield of rice hybrid variety CoRH2. They suggested that N supplied at 7 DAT, 21 DAT, panicle initiation stage and first flowering stage gave the highest filled grains.

Lang *et al*. (2003) found that the increase in nitrogen fertilizer application rate enhanced grains per panicle, effective panicles per plant, and total florets per plant in rice.

Meena *et al*. (2002) noted that increase in nitrogen fertilizer application rate enhanced number of grains and filled grains of hybrid rice.

Hussain and Sharma (1991) stated that application of nitrogen increased grain number $panicle^{-1}$ in rice up to 80 kg N $ha^{-1}$. Nitrogen application at the rate of 120 kg $ha^{-1}$ did not significantly affect the grains $panicle^{-1}$. The highest grain number $panicle^{-1}$ produced at 80 kg N $ha^{-1}$ and the lowest was produced at the control.

### 2.3.4 1000-grain weight

Maiti *et al.* (2003) conducted an experiment to study the effects of nitrogen fertilizer rate (0, 120, and 140 kg ha$^{-1}$) on the performance of 1 cultivar (IET-4786) and 4 hybrid varieties (ProAgro 6Y213, ProAgro 6Y3024, ProAgro 6111N, and ProAgro 6201) of rice. The nitrogen fertilizer was applied during transplanting (50%) and at the tillering and panicle initiation stages (50%). They reported that the application of 140 kg N ha$^{-1}$ resulted in the highest increase in grain yield (by 76.2%), number of panicles (by 109.00%), number of filled grains per panicle (by 26.2%), and 1000-grain weight (5.80%) over the control, and the highest nitrogen (136.701 kg ha$^{-1}$), phosphorus (132.029 kg ha$^{-1}$), and potassium (135.167 kg ha$^{-1}$) uptake.

Meena *et al.* (2002) reported that increase in nitrogen fertilizer application rate increased 1000-grain weight of hybrid rice.

Hasan *et al.* (2002) determined the response of hybrid (Sonar Bangla-1 and Alok 6201) and inbred (BRRI Dhan34) rice varieties to the application methods of urea super granules (USG) and prilled urea (PU) and reported that the effect of application method of USG and PU was not significant in respect of panicle length, number of unfilled grains panicle$^{-1}$ and 1000-grains weight.

Ahmed *et al.* (2000) conducted a field experiment to study the effect of point placement of urea super granules (USG) and broadcasting prilled urea (PU) as sources of N in T. Aman rice. USG and PU were applied @ 40, 80, 120 or 160 Kg N ha$^{-1}$. They suggested that USG was more efficient than PU in producing panicle length, filled grains panicle$^{-1}$ and 1000-grain weight.

Thakur (1991) observed that yield attributes of rice differed significantly due to the levels and sources of nitrogen fertilizer. At 60 kg N ha$^{-1}$ application through USG produced the highest panicle weight, grain number panicle$^{-1}$, 1000- grain weight of rice.

Islam *et al*. (1990) reported that there was an increasing trend of 1000-grain weight in rice with an increase in levels of nitrogen fertilizer application up to 80 kg $ha^{-1}$.

Rafey *et al*. (1989) found that application of nitrogen from 0–60 kg $ha^{-1}$ increased 1000 grain weight linearly. The highest weight of 1000-grain was obtained from 60 kg N $ha^{-1}$ and the lowest from the control.

Kumar *et al*. (1986) found that increasing rates of N from 0–80 kg $ha^{-1}$ increased the number of tillers $hill^{-1}$, grain number $panicle^{-1}$ and 1000-grain weight.

Rahman *et al*. (1985) concluded that nitrogen rate had no significant influence on grains $panicle^{-1}$ and 1000-grain weight of rice.

### 2.3.5 Grain yield

BRRI (2009) conducted an experiment to study the N release pattern from USG and prilled urea under field condition and its effect on grain yield and N nutrition of rice. Three doses of N namely 50, 100 and 150 kg N $ha^{-1}$ from two types of urea e.g. prilled (PU) and urea super granules (USG) were tested as treatment. Results showed that the highest grain yield was recorded when N applied @ 100 kg N $ha^{-1}$ both from USG and PU and the highest straw yield was obtained in PU @ 150 kg N $ha^{-1}$.

BRRI (2008 b) conducted an experiment to study on the of response of MVs and hybrid entries to added N in a rice-rice cropping pattern. Six N doses (0, 40, 80, 120, 160 and 120 kg N $ha^{-1}$) were tested and resulted that grain yield of hybrid responded up to 120 kg N $ha^{-1}$.

Kabir *et al*. (2009) conducted an experiment to investigate the effect of urea super granules (USG), prilled urea (PU) and poultry manure (PM) on the yield and yield contributes of transplant Aman rice. They observed that the highest grain yield (5.17 t ha$^{-1}$), straw yield (6.13 t ha$^{-1}$) and harvest index (46.78%) were found from full dose of USG.

Lin *et al*. (2008) conducted an experiment to observe the effect of plant density and nitrogen fertilizer rates (120, 150, 180 and 210 kg N ha$^{-1}$) on grain yield and nitrogen uptake of hybrid rice. They observed that there was a better response to N fertilization, as increasing N application from 120 to 180 kg N ha$^{-1}$ (by 50%) raised yield by 17%. Raising the application rate to 210 kg N ha$^{-1}$ (by 75%) boosted yield by 24.1%.

Wan *et al*. (2007) conducted field experiments to study the effects of different nitrogen (N) fertilizer application regimes (basal and panicle applications) on the yield, quality and N use efficiency of super *japonica* hybrid rice cv. Changyou 1. They indicated that yield was significantly influenced by different N fertilizer application regimes. The regime with the highest yield was at the basal to panicle application ratio of 58.34 : 41.66 and equal split of panicle applications at the fourth and second leaf age from the top.

Mubarak and Bhattacharya (2006) conducted a study to investigate the response of hybrid rice cultivars to various levels of nitrogen and potassium. Significantly higher values for growth and grain yield were obtained with the application of 150 : 60 : 80 kg NPK ha$^{-1}$, which was at par with 150 : 60 : 40 kg NPK ha$^{-1}$.

Ingale *et al*. (2005) conducted a study to determine the effects of seedling ages at transplanting (25, 40 and 55 days), number of seedlings per hill (one or two) and nitrogen rates (50, 100 and 150 kg ha$^{-1}$) on the yields of Sahyadri rice hybrid. They found that the application of 150 and 100 kg N ha$^{-1}$ resulted in significantly higher grain yields than treatment with 50 kg N ha$^{-1}$.

Rakesh *et al*. (2005) conducted a field experiment to determine the response of hybrid rice cv. MPH-501 to different nitrogen (40, 80, 120 and 160 kg N ha$^{-1}$) and potassium levels (30, 60, and 90 kg $K_2O$ ha$^{-1}$). The application of 160 kg N and 60 kg $K_2O$ $ha^{-1}$ significantly influenced the growth and yield attributes of hybrid rice and produced higher grain and straw yield.

BRRI (2004) concluded that nitrogen fertilizer when applied as USG was reported to have increased grain yield by around 18% and saved around 32% N in wetland rice over prilled urea and appeared to be a good alternative N fertilizer management for rice production.

Upendra *et al*. (2004) conducted a field experiment to evaluate two newly developed rice hybrids (KHR2 and DRRH1) and one local control (Boro 5) growth under 10 different nitrogen-potassium (NK) fertilizer levels. Both rice hybrids performed better than the local cultivar. Yield and related characters increased with increasing fertilizer levels up to 150 kg N $ha^{-1}$ and 80 kg K $ha^{-1}$.

Verma *et al*. (2004) conducted a study to investigate the effect of planting date (20 July and 5 and 20 August) and N rates (50, 100 and 150 kg $ha^{-1}$) on hybrid rice. They revealed that N at 100 and 150 kg $ha^{-1}$ resulted in the highest yield.

Singh and Shivay (2003) found that increasing levels of nitrogen significantly increased the grain and straw yields in hybrid rice.

Maiti *et al*. (2003) reported that the application of 140 kg N $ha^{-1}$ resulted in the highest increase in grain yield of rice.

Balasubramanian (2002) conducted a field experiment to study the effect of levels (0, 150, 200 and STCR-based N) and time of application (3 or 4 splits) of nitrogen on 'CoRH 1' hybrid rice. Hybrid rice recorded good response to N up to 256.7 kg $ha^{-1}$ (STCR-based N). Higher levels of N improved the growth and yield of rice. The STCR-based N applied in 4 splits (basal, active tillering, panicle initiation and panicle emergence) registered the maximum grain yield, followed by 200 kg N $ha^{-1}$ applied in 4 splits.

Duhan and Singh (2002) reported that the rice yield and uptake of nutrients increased significantly with increasing N levels. Moreover, the application of nitrogen from chemical fertilizer along with various green manuring (GM) showed additive effects on yield and uptake of nutrients. Under all green manuring treatments, the yield and uptake were always higher with 120 kg $ha^{-1}$ than with lower level of nitrogen.

Meena *et al*. (2002) reported that application of nitrogen significantly increased grain and straw yields of hybrid rice up to the level of 200 kg N $ha^{-1}$.

Angayarkanni and Ravichandran (2001) conducted a field experiment to determine the best split application of 150 kg N $ha^{-1}$ for rice cv. IR20. They found that applying 16.66% of the recommended N as basal, followed by 33.33% N at 10 DAT (days after transplanting) 25% N at 20 days and 25% at 40 DAT (days after transplanting) recorded the highest grain (6189.4 kg $ha^{-1}$) and straw (8649.6 kg $ha^{-1}$) yields, response ratio (23.40) and agronomic efficiency (41.26).

Devasenamma *et al*. (2001) conducted a field experiment to study the performance of rice hybrids (APHR-2, DRRH-1, MGR-1, TNRH-16 and NLR-33358) at various N fertilizer rates (0, 60, 120 and 180 kg $ha^{-1}$). The highest values for yield and yield components were obtained with 180 kg N $ha^{-1}$.

Ahmed *et al.* (2000) revealed that USG was more efficient than PU at all respective levels of nitrogen in producing grain and straw yields. Placement of USG @ 160 Kg N $ha^{-1}$ produced the highest grain yield (4.32 t $ha^{-1}$) which was statistically identical to that obtained from 120 kg N $ha^{-1}$.

Singh *et al*. (2000) stated that each incremental dose of N gave significantly higher yield of rice. The crop fertilized with 100 kg N $ha^{-1}$ gave the maximum grain yield (2647 kg $ha^{-1}$).

Rajendran and Veeraputhiran (1999) suggested that grain yield of hybrid rice increased as the N rate increased. The highest straw yield (13.1 t $ha^{-1}$) was found with 225 kg N $ha^{-1}$.

Balaswamy (1999) in an experiment with deep placement of nitrogen as urea super granules recorded that USG reduced the dry weight of weeds resulting in more panicles and filled grains and increased the grain yield of rice over the split application of prilled urea by 0.43 and 0.3 t $ha^{-1}$ and basal application of large granular urea by 0.73 and 0.64 t $ha^{-1}$, respectively.

Behera (1998) conducted a field experiment on scented rice during rainy seasons of 1993, 1994 and 1995 applying 0, 30, 60, 90 and 120 kg N $ha^{-1}$ and found that the yield increased 12.9, 22.3, 28.5 and 31% over control, respectively. He observed that HKR 228 gave the higher grain yield and HKR 228 was superior to other cultivars for panicles $m^{-2}$ and gave a higher grain yield. They also found that all the growth and yield forming characters increased linearly up to 90 kg N $ha^{-1}$ and thereafter grain yield increased marginally.

Choudhuri *et al*. (1998) in an experiment with three rice cultivars Haryana Basmati, Kashiri, and Pusa Basmati with 0–100 kg N $ha^{-1}$ found that mean grain yield was the highest (2.90 t $ha^{-1}$) with 100 kg N $ha^{-1}$.

Islam and Black (1998) along with Department of Agricultural Extension, conducted 432 demonstrations in 72 Upazila of 31 districts in Bangladesh on Boro rice. It was reported that USG plots, on an average, produced nearly 5% higher yields than the PU treated plots while applying 30–40% less urea in the form of USG.

Singh *et al.* (1998) evaluated the performance of three F1 hybrid rice cultivars (KHR 1, Pro. Agro. 103 and MGR 1) using Jaya and Rasi as standard checks giving four levels of N (0, 60, 120 and 180 kg $ha^{-1}$) and noticed that grain yields of rice increased linearly with increasing N levels up to 120 kg $ha^{-1}$.

Hari *et al.* (1996) pointed out that grain yield of rice was increased as nitrogen fertilizer application increased from 0 to 150 kg $ha^{-1}$, although a further increase up to 200 kg $ha^{-1}$ did not increase grain yield.

Kumar *et al*. (1996) observed that increment of grain yield of rice at 160 kg N $ha^{-1}$ over the control treatment was 42.0%.

Maskina *et al*. (1996) stated that paddy yield increased with the application of nitrogen up to 100 kg $ha^{-1}$ and then decreased with increasing rate of nitrogen fertilizer.

Panda *et al*. (1996) showed that N fertilizer application significantly increased the grain yield of rice.

Hossain *et al*. (1995) observed that application of nitrogen up to 120 kg $ha^{-1}$ increased the grain yield of rice. Increase in yield with 40, 80 and 120 kg N $ha^{-1}$ over the control was 24, 33 and 34%, respectively. They noted significantly higher yields with 80 and 120 kg N $ha^{-1}$ than 0 and 40 kg N $ha^{-1}$.

Mukherjee and Mandal (1995) conducted a field experiment to study the effect of complete submergence on yield and nitrogen in rice. Rice cv. Raina was used as test crop. 100 kg N $ha^{-1}$ as urea in 2–3 splits was given with in 3 different ratios i.e. 90: 10: 0, 70: 20: 10 and 50: 30: 20 at transplanting, tiller initiation and panicle initiation, respectively. They found that grain yields were 20% higher over control plots.

Singh and Pillai (1994) stated that increased doses of nitrogen fertilizer increased grain yield significantly up to 90 kg $ha^{-1}$, after which it declined.

Virdia *et al*. (1993) observed that rice cultivar Masuri and 1-30-1-1 with applying 150 kg N $ha^{-1}$ gave the highest grain yield of 5.94 t $ha^{-1}$.

BRRI (1992) reported that both grain and straw yields of rice increased significantly up to 80 kg N $ha^{-1}$. Application of nitrogen from 120 to 160 kg N $ha^{-1}$ significantly reduced the yield which was assumed to be due to excessive vegetative growth followed by lodging after flowering in rice plants.

Raju and Reddy (1992) observed that nitrogen and phosphorus fertilization had a significant effect on yield components. Application of 80 and 120 kg N $ha^{-1}$ markedly improved the grain yield by 17% and 45.9%, respectively.

Singh and Singh (1986) conducted a field experiment on dwarf rice cv. Jaya where N was given as 90 or 120 kg N $ha^{-1}$ as urea super granules, large granular urea or neem cake coated urea. N was applied basally, or in 2 equal splits (basally and panicle initiation). They found that grain yield was the highest with 120 kg N (4.65 t $ha^{-1}$), was not affected by N source and was higher with split application.

Kumar *et al.* (1995) reported that application of USG in the sub-soil gave 22% higher grain yield than control treatment in rice.

Rashid *et al.* (1996) conducted field experiments in two locations of Gazipur district to determine the nitrogen use efficiency of urea super granules (USG) and prilled urea (PU) in irrigated rice cultivation. It was observed that 87 kg N $ha^{-1}$ from USG produced the highest grain yield. However, 58 kg N $ha^{-1}$ from USG and 87 kg N $ha^{-1}$ from PU produced statistically similar grain yield to that of 87 kg $ha^{-1}$ from USG.

### 2.3.6 Straw yield

Patel and Mishra (1994) stated that application of 0, 30, 60, 90 kg N $ha^{-1}$ increased grain and straw yields.

Murty *et al*. (1992) observed that the grain yields were 3.5, 4.2, 5.1, 5.5 t $ha^{-1}$ and the straw yields were 4.2, 4.8, 6.0, 6.4 t $ha^{-1}$, respectively by applying 0, 40, 80 and 120 kg N $ha^{-1}$ in rice field.

Idris and Matin (1990) observed that increasing different levels of nitrogen increased the yield of grain and straw of rice.

Hussain *et al*. (1989) concluded that straw yield of rice increased up to 9.1 t $ha^{-1}$ with increasing N rate.

Srivastava *et al*. (1987) observed that higher doses of N produced higher amount of straw and grain in transplanted rice.

## 2.4 Effect of zinc application on rice

Mia (2018) conducted a field experiment 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 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.

Podder (2017) conducted a field experiment to find out the response of Boro rice to foliar spray of zinc and boron. BRRI dhan29 was used as testing variety. The treatments were $T_1$ = Recommended Fertilizer (RF), $T_2$ = RF + Foliar spray (FS) with water at tiller initiation (TI), $T_3$ = RF + Foliar spray (FS) with water at flowering initiation (FI), $T_4$ = Zn (0.2%) FS at TI + RF, $T_5$ = Zn (0.5%) FS at TI + RF, $T_6$ = Zn (0.8%) FS at TI + RF, $T_7$ = Zn (0.2%) FS at FI + RF, $T_8$ = Zn (0.5%) FS at FI + RF, $T_9$ = Zn (0.8%) FS at FI + RF, $T_{10}$ = B (0.5%) FS at TI +

RF, $T_{11}$ = B (1.5%) FS at TI + RF, $T_{12}$ = B (2.0%) FS at TI + RF, $T_{13}$ = B (0.5%) FS at FI + RF, $T_{14}$ = B (1.5%) FS at FI + RF, $T_{15}$ = B (2.0%) FS at FI + RF. Among the zinc foliar spray treatments, the maximum Leaf Area Index (LAI) (3.14), number of effective tillers hill$^{-1}$ (13.24), Panicle length (24.49 cm), number of filled grains panicle$^{-1}$ (136.73), the highest grain yield of rice (6.33 t ha$^{-1}$), straw yield (7.09 t ha$^{-1}$), biological yield (13.42 t ha$^{-1}$) and harvest index (47.17%) was recorded from $T_4$ treatment [Zn (0.2%) foliar spray at tiller initiation stage + Recommended Fertilizer]. 1000-grains weight (g) of rice was not varied significantly due to different treatments but numerically the maximum weight of 1000-grains (28.60 g) was recorded from $T_5$ treatment [Zn (0.5%) FS at TI + RF].

Islam (2015) carried out an experiment to study the effect of zinc and boron on the growth and yield of T. Aman rice (BRRI dhan34). Two factors were comprised with study viz. factor A: $B_0$ = 0 kg B ha$^{-1}$, $B_1$ = 2 kg B ha$^{-1}$ and $B_2$ = 4 kg B ha$^{-1}$ and Factor B: $Zn_0$ = 0 kg Zn ha$^{-1}$, $Zn_1$ = 2 kg Zn ha$^{-1}$ and $Zn_2$ = 4 kg Zn ha$^{-1}$. Results indicated that the highest straw weight ha$^{-1}$ (8.07 t) was recorded from $B_1Zn_1$; the number of total tiller hill$^{-1}$ (19.81) and effective tiller hill$^{-1}$ (14.53) were received from $B_1Zn_0$. Again, the longest panicle (25.28 cm), filled grain panicle$^{-1}$ (143.60), total grain panicle$^{-1}$ (161.40), grain weight ha$^{-1}$ (5.72 t ha$^{-1}$) and harvest index (45.77%) were recorded from $B_2Zn_2$. The tallest plant (132.30 cm), non-effective tiller hill$^{-1}$ (5.55) and un-filled grain panicle$^{-1}$ (56.52) were achieved from the treatment combination of $B_1Zn_2$, $B_0Zn_2$ and $B_0Zn_0$ respectively. The treatment combination $B_2Zn_2$ performed better for increasing the yield of T. Aman rice and improved the nutrient status of post-harvest soil of AEZ 28.

Sharmin (2014) conducted an experiment to find out the influence of sulphur and zinc on yield of transplanted (T.) Aman rice. BRRI dhan34 was used as the test crop in this experiment. The experiment consisted of two factors. Factor A: 3 levels of sulphur ($S_0$: 0 kg S ha$^{-1}$, $S_1$: 8.0 kg S ha$^{-1}$, $S_2$: 12.0 kg S ha$^{-1}$) and Factor B: 4 levels of zinc ($Zn_0$: 0 kg Zn ha$^{-1}$, $Zn_1$: 1.0 kg Zn ha$^{-1}$, $Zn_2$: 2.0 kg Zn ha$^{-1}$,

$Zn_3$: 3.0 kg Zn $ha^{-1}$). For different levels of zinc, the highest yield and yield contributing characters were observed were recorded from $Zn_3$, whereas the lowest was recorded from $Zn_0$. Due to the interaction effect of different levels of sulphur and zinc, at 30, 45, 60, 75 DAT and harvest, the tallest plant (26.65, 54.48, 87.32, 98.67 and 122.53 cm, respectively), the maximum number of total tillers $hill^{-1}$ (20.60), the longest panicle (29.65 cm), the highest grain yield (4.00 t $ha^{-1}$), the highest straw yield (5.36 t $ha^{-1}$) and the maximum uptake by grain for N (38.45 kg $ha^{-1}$), P (15.93 kg $ha^{-1}$), K (19.79 kg $ha^{-1}$), S (6.36 kg $ha^{-1}$) and Zn (0.819 kg $ha^{-1}$) were recorded from $S_2Zn_3$, whereas the shortest plant (16.89, 45.09, 63.66, 81.05 and 103.81 cm, respectively), the minimum number of total tillers $hill^{-1}$ (13.13), the shortest panicle (20.23 cm), the lowest grain yield (2.13 t $ha^{-1}$), lowest (3.88 t $ha^{-1}$) and the minimum uptake by grain for N (12.55 kg $ha^{-1}$), P (6.08 kg $ha^{-1}$), K (9.85 kg $ha^{-1}$), S (3.48 kg $ha^{-1}$) and Zn (0.287 kg $ha^{-1}$) was recorded from $S_0Zn_0$. Therefore, a package of 8.0 kg S $ha^{-1}$ along with 2.0 kg Zn $ha^{-1}$ was recommended for T. Aman cultivation in Shallow Red Brown Terrace Soil under Madhupur Tract (AEZ-28) of Dhaka district.

Oahiduzzaman (2013) conducted an experiment to study the effect of zinc and cow dung on growth, yield and nutrient content of transplanted Aman rice. BRRI dhan33 was used as the test crop in this experiment. The experiment consisted of two factors. Factor A: 4 levels of zinc ($Zn_0$: 0 kg Zn $ha^{-1}$ (control), $Zn_1$: 2.0 kg Zn $ha^{-1}$, $Zn_2$: 3.0 kg Zn $ha^{-1}$, $Zn_3$: 4.0 kg Zn $ha^{-1}$) and Factor B: 4 levels of cow dung ($C_0$: 0-ton cow dung $ha^{-1}$ (control). $C_1$: 4.50-ton cow dung $ha^{-1}$, $C_2$: 5.0-ton cow dung $ha^{-1}$ and $C_3$: 5.5-ton cow dung $ha^{-1}$). For 4.0 kg Zn $ha^{-1}$ ($Zn_3$), the tallest plant (25.12, 41.09, 58.90, 75.03 and 88.34 cm) were recorded at 30, 50, 70, 90 days after transplanting (DAT) and at harvest, respectively. On the other hand, the shortest plant (19.95, 33.52, 51.08, 65.25 and 80.50 cm) were found from control treatment ($Zn_0$) at 30, 50, 70, 90 DAT and at harvest, respectively. The maximum number of effective tillers $hill^{-1}$ (13.30) was observed from $Zn_3$ and the minimum number (10.18) from $Zn_0$. The highest grain yield $ha^{-1}$ (5.11 ton) was found from $Zn_3$ and the lowest grain yield $ha^{-1}$ (3.28

ton) from $Zn_0$.

Tahura (2011) conducted a field experiment with the objective of evaluating the effect of S and Zn on the yield performance and nutrient content of T-Aman Rice. The experiment composed of four different individual and combined treatment (sixteen) of sulphur *viz.* $S_0$ (control). $S_8$ (8 kg $ha^{-1}$), $S_{12}$ (12 kg $ha^{-1}$) and $S_{16}$ (16 kg $ha^{-1}$) and zinc *viz.* $Zn_0$ (0 kg $ha^{-1}$), $Zn_{1.0}$ (1.0 kg $ha^{-1}$), $Zn_{1.5}$(1.5 kg $ha^{-1}$) and $Zn_{2.0}$ (2.0 kg $ha^{-1}$). The tallest plant (124.0 cm), highest grain yield (5.663 t $ha^{-1}$) and straw yield (8.163 t $ha^{-1}$) of T-Aman Rice was recorded in $S_{12}Zn_{1.5}$ (12 kg S $ha^{-1}$ + 1.5 kg Zn $ha^{-1}$). Overall results indicate that the treatment combination of $S_{12}Zn_{1.5}$ (12 kg S $ha^{-1}$ and 1.5 kg Zn $ha^{-1}$) alone or combinedly was more effective to produce higher yield of T-Arran rice supported with recommended doses of N, P, and K.

Rahman (2007) conducted a field experiment with an objective of evaluating the effect of S and Zn on the yield, yield components and nutrient uptake by T-Aman (BRRI dhan31). There were twelve treatments taking various doses of Sulphur and Zinc viz. $S_0Zn_0$ (control), $S_0Zn_1$, $S_0Zn_2$, $S_{12}Zn_0$, $S_{12}Zn_1$, $S_{12}Zn_2$, $S_{16}Zn_0$, $S_{16}Zn_1$, $S_{16}Zn_2$, $S_{20}Zn_0$, $S_{20}Zn_1$ and $S_{20}Zn_2$. The subscripts represent doses in kg/ha. The application of Sulphur and Zinc had a positive significant effect on tillers $hill^{-1}$, plant height, panicle length and no. of grains $panicle^{-1}$. The highest grain yield (4.20 t $ha^{-1}$) and straw yield (5.62 t $ha^{-1}$) of BRRI dhan31 was recorded in $S_{20}Zn_2$ treatment. The $S_0Zn_0$ treatment (control) had the lowest grain (3.01 t $ha^{-1}$) and straw yield (4.50 t $ha^{-1}$). Overall results indicate that the application of Sulphur and Zn at a rate of 20 kg S and 2 kg Zn $ha^{-1}$ along with recommended dose of N, P, and K is necessary for obtaining maximum grain yield as well as straw yield of T-Aman rice.

Sarker (2007) conducted a field experiment to find out the performance of Aman rice as influenced by nitrogen and zinc on the yield of BRRI Dhan 39. There were 16 treatments combinations comprising of four levels of N (0, 50, 100 and 150 kg N ha$^{-1}$) and four levels of Zn (0, 5, 10 and 15 kg Zn ha$^{-1}$). The tallest plant (112 cm), total number of tiller plant$^{-1}$ (12.16), number of effective tiller plant$^{-1}$ (11.79), panicle length plant$^{-1}$ (23.80 cm). number of filled grain panicle$^{-1}$ (88.46) and grain yield (4.91 t ha$^{-1}$) were recorded under the treatment of 100 kg N ha$^{-1}$. Straw yield increased significantly up to 150 kg N ha$^{-1}$, but the grain yield showed a significant negative effect at this rate of N application. Plant height, total tillers, effective tillers and panicle length increased significantly with increasing Zn application up to 5 kg Zn ha$^{-1}$, while the number of filled grain panicle$^{-1}$, grain yield and straw yield enhanced with increasing Zn doses up to 10 kg Zn ha$^{-1}$. However, the application of 15 kg Zn ha$^{-1}$ had a significant negative effect on grain yield but not on straw yield. The $T_{11}$ ($N_2Zn_2$) treatment combination at the rate of 100 kg N ha$^{-1}$ and 10 kg Zn ha$^{-1}$ perform better than other treatments in this present trial considering rice yield and yield contributing parameters. The interaction effect of different doses of nitrogen and zinc showed statistically significant differences in consideration of total tiller, effective tiller, filled grain and grain yield of rice. From the viewpoint of grain yield of rice and the nutrient requirement of the crop, the N and Zn combination ($N_2Zn_2$) at the rate of 100 kg N ha$^{-1}$ and 10 kg Zn ha$^{-1}$ was considered to be the balanced combination or fertilizer for the maximum output through cultivation of rice in Deep Red Brown Terrace Soil.

Islam (2005) conducted a field experiment to evaluate the effect of organic manures (FYM + PM) and zinc fertilizer on yield attributing characters, yield, nutrient contents and their uptake in transplanted Aman rice (BRRI dhan30). The experiment was laid-out comprising 3 levels of organic manures (0, FYM 12 t ha$^{-1}$, PM 3 t ha$^{-1}$) and 3 levels of zinc fertilizer (0, 12, 15 kg ha$^{-1}$). Zinc sulphate ($ZnSO_4$) was used as the source of zinc fertilizer. The individual effect of zinc had significant positive impact on the different morphological character, grain and straw yield of rice. The highest number of tillers hill$^{-1}$ (11.13), the highest number of effective tillers hill$^{-1}$ (10.23), the longest panicle (23.96 cm), the maximum grain number panicle$^{-1}$ (111.90), the maximum weight of 1000-grains (20.50g), the highest grain yield (4.67 t ha$^{-1}$) and straw yield (7.00 t ha$^{-1}$) was obtained from $Z_{12}$ treatment (12 kg Z ha$^{-1}$), which is the recommended optimum dose for rice.

Sultana (2005) was conducted a field experiment with an objective of evaluating the effects of S and Zn on the yield, yield components and nutrient uptake of Boro rice (cv. BRRI dhan 29). There were seven treatments taking various doses of S and Zn viz. $S_0Zn_0$ (control), $S_{20}Zn_0$, $S_0Zn_3$, $S_{20}Zn_3$, $S_{10}Zn_0$, $S_oZn_{1.5}$ and $S_{10}Zn_{1.5}$, the subscripts represent doses in kg ha$^{-1}$. The application of S and Zn had a significant positive effect on the tillers hill$^{-1}$, plant height, panicle length and grains panicle$^{-1}$. The highest grain (5110 kg ha$^{-1}$) and straw yields (5812 kg ha$^{-1}$) of rice were recorded in the $S_{20}Zn_3$ treatment (country's recommended dose). The $S_0Zn_0$ (control) treatment had the lowest grain (2832 kg ha$^{-1}$) and straw yields (3199 kg ha$^{-1}$). Overall results indicate that the application of S and Zn at a recommended rate i.e. 20 kg S and 3 kg Zn ha$^{-1}$ along with recommended rate of N, P and K is necessary for obtaining higher grain yield as well as straw yield of Boro rice.

## 2.5 Effect of zinc application on Crop growth parameters of rice

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

Ghoneim (2016) observed that different methods of Zn application significantly increased the tiller number over control. The increase in tiller number by soil application of Zn might be attributed due to increase of nutrients availability in soil compared with other treatments.

Rahman *et al*. (2008) carried out a field investigation on Boro rice with seven treatments viz. $T_1$: $S_0Zn_0$ (control), $T_2$: $S_{10}Zn_0$, $T_3$: $S_{20}Zn_0$, $T_4$: $S_0Zn_{1.5}$, $T_5$: $S_0Zn_3$, $T_6$: $S_{10}Zn_{1.5}$ and $T_7$: $S_{20}Zn_3$. The experimental result indicated that, number of tillers in Boro rice plant was significantly affected due to application S and Zn.

Boonchuay *et al*. (2013b) 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 number of tillers plant$^{-1}$ (17) and plant dry matter (50.1 g plant$^{-1}$). The lowest tillers plant$^{-1}$ (10) and plant dry matter (41.1 g plant$^{-1}$) was recorded in control where there was no foliar application of zinc.

Kabeya and Shanker (2013) recorded that the treatment receiving 30 kg $ZnSO_4$ ha$^{-1}$ showed the highest SPAD (Soil Plant Analysis Development) value (57) in rice. The highest straw dry matter (41 g) and leaf dry matter (28 g) in rice was also obtained from this treatment, the lowest was obtained in control.

Muthukumararaja and Sriramachandrasekharan (2012) reported that maximum amount of dry matter production of rice plant at tillering (2.98 g pot$^{-1}$) and at panicle initiation stage (40.93 g pot$^{-1}$) 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.

Sriramachandrasekharan and Mathan (2012) and Chaudhary and Sinha (2007) reported that the highest amount of dry matter (28.25 g hill$^{-1}$) and the lowest amount of dry matter (7.28 g hill$^{-1}$) in rice was accumulated in case of $Zn_4$ (6 kg) and $Zn_1$ (0 kg) treatment at maturity and tillering, respectively.

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 maximum number of tillers plant$^{-1}$(17.41) in rice.

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

Khan *et al.* (2003) observed that the maximum number of tillers $m^{-2}$ (415.67) in rice field 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.

Hossain *et al.* (2001) reported that the application of Zn in combination with B and Mo significantly produced the longer panicle length (24.4 cm) in rice. The shortest panicle was observed in control which did not receive zinc application.

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 amount of dry matter production in transplanted rice.

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

Several researchers observed that soil application of zinc sulphate significantly enhanced the amount of dry matter production in rice over no zinc application (Channal and Kandaswamy, 1997; Pulla and Shukla, 1996; Agarwal and Gupta, 1994; Mali and Shaikh, 1994 and Mehdi *et al*., 1990).

Raju *et al.* (1994) did not observe any significant increase in the amount of dry matter production in rice field 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.

Singh and Sharma (1994) noticed that basal dressing of all zinc carriers gave significantly higher number of tillers $m^{-2}$ than foliar spray of zinc in rice fields on salt affected silty clay soils of U.P.

Tomar *et al*. (1994) concluded that application of $ZnSO_4$ @ 75 kg $ha^{-1}$ significantly increased the dry matter production (63.60 q $ha^{-1}$) of rice plants on clay loam soils of Khandwa, M.P.

## 2.6 Effect of zinc application on yield and yield contributing parameters

Apoorva (2016) observed that the highest mean values of yield and its components, i.e. number of panicles $m^{-2}$ (446.6), the number of filled grains $panicle^{-1}$ (13.3), the highest grain yield (5355 kg $ha^{-1}$) and the highest straw yield (6347kg $ha^{-1}$) were recorded from 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 $ZnSO_4$ and RDF + foliar application of 1 ml Zn as Nano zinc.

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 $m^{-2}$ in rice plants 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 from 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 was observed between Zn application methods.

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 $panicle^{-1}$ in rice plants, but, it was at par with the application of 40 kg $ZnSO_4$ $ha^{-1}$ alone on sodic soils of U.P.

Alam and Kumar (2015) investigated to evaluate the effect of Zinc on growth and yield of rice var. Pusa Basmati-1. The experiment was laid out with four treatments (0 kg $ha^{-1}$ $ZnSO_4$, 5 kg $ha^{-1}$ $ZnSO_4$, 10 kg $ha^{-1}$ $ZnSO_4$ and 20 kg $ha^{-1}$ $ZnSO_4$). The result revealed that the maximum panicle length (23.39 cm), the maximum number of effective tillers $m^{-2}$ (317) were obtained from 10 kg $ha^{-1}$ $ZnSO_4$ and the minimum panicle length (16.57 cm), the minimum number of effective tillers $m^{-2}$ (225) were obtained from 0 kg $ha^{-1}$ $ZnSO_4$. The maximum weight of 1000-grains (24.97 g) was obtained from 10 kg $ha^{-1}$ $ZnSO_4$ and the minimum weight of 1000-grains (22.25 g) was obtained from 0 kg $ha^{-1}$ $ZnSO_4$. The maximum grain yield (32.45 q $ha^{-1}$) was obtained from 10 kg $ha^{-1}$ $ZnSO_4$ and the minimum grain yield (24.32 q $ha^{-1}$) was obtained from 0 kg $ha^{-1}$ $ZnSO_4$. The maximum straw yield (69.25 q $ha^{-1}$) was obtained from 10 kg $ha^{-1}$ $ZnSO_4$ and the minimum straw yield (46.37 q $ha^{-1}$) was obtained from 0 kg $ha^{-1}$ $ZnSO_4$.

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

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 (22.7 g) of rice 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.

Boonchuay *et al*. (2013a) 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 (20.1 g $plant^{-1}$), straw weight (30.1 g $plant^{-1}$), panicles $plant^{-1}$ (13) and the lowest was seen in control where there was no foliar application.

Ali *et al.* (2012) and Singh *et al.* (2012) from their corresponding study stated that maximum rice yield (7.63 t ha$^{-1}$) was recorded with combined application of 30 kg sulphur and 6 kg zinc ha$^{-1}$. This combined analysis suggested that for better output and for balanced nutrition combined application is advocated.

Dixit *et al*. (2012) observed that application of Zn at 25 kg ha$^{-1}$ in rice significantly increased the panicle length (24.96 cm), grain yield (60.34 q ha$^{-1}$), straw yield (77.37 q ha$^{-1}$) with significant difference from 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 of rice were observed in treatment consisting of NPK + 20 kg Zn ha$^{-1}$ compared with NPK alone.

Singh *et al*. (2012) observed that the maximum amount of dry matter weight (28.25 g hill$^{-1}$) and grain yield (7.5 t ha$^{-1}$) of rice were recorded with application of Zn @ 6 kg and the minimum dry matter (7.8 g hill$^{-1}$) and grain yield (6.0 t ha$^{-1}$) were seen in control.

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 was evident that the highest grain number panicle$^{-1}$ (118.66), 1000 grain weight (23.93 g) 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.

Reddy *et al*. (2011a) and Khan *et al*. (2003) stated that there was no significant impact observed on 1000-grain weight of rice from zinc application methods (basal and foliar spray) on a partially reclaimed sodic soil at Faizabad.

Prasad *et al.* (2010) reported that the highest grain yield (4.35 t $ha^{-1}$) and straw yield (7.27 t $ha^{-1}$) were recorded under 100% crop residue level and 10 kg Zn $ha^{-1}$ in rice compared with 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.

Maqsood *et al.* (2008) conducted this study 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, $ZnSO_4$ application at the rate of 25 kg $ha^{-1}$ 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, kernel yield and harvest index. Maximum rice yield (5.21 t $ha^{-1}$) was achieved in treatment $Zn_1$ (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 increased the crop growth rate of rice.

Rahman *et al.* (2008) carried out a field investigation with Boro rice having seven treatments viz. $T_1$: $S_0Zn_0$ (control), $T_2$: $S_{10}Zn_0$, $T_3$: $S_{20}Zn_0$, $T_4$: $S0Zn_{1.5}$, $T_5$: $S_0Zn_3$, $T_6$: $S_{10}Zn_{1.5}$ and $T_7$: $S_{20}Zn_3$. The experimental result indicated that, panicle length was significantly affected to S and Zn application. The longest Panicle (25.26 cm) was obtained from $S_{20}Zn_3$ and the shortest (22.73 cm) was recorded 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 were not significant with various treatments. The 1000-grain weight followed the order $T_4 > T_2 > T_7 > T_5 > T_3 > T_6 > T_1$. 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 $S_0Zn_0$.

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

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.

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

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 $m^{-2}$ in rice field but it was on a par with soil application and root dip treatments.

Ram *et al*. (2005) observed the maximum number of filled grains $panicle^{-1}$ in rice plants were from the treatment that received combined application of 20 kg $ZnSO_4$ $ha^{-1}$ as basal + three times foliar sprays of 0.5% $ZnSO_4$ solution initiated from 20 DAT at 10 days interval but it was at a par with separate application of $ZnSO_4$ as soil and foliar spray on partially reclaimed sodic or silty loam soils of Faizabad (U.P.).

Ravikiran and Reddy (2004) found that foliar spray of Zn increased the 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 in rice field.

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 of rice on loamy soil of New Delhi.

Rahman *et al*. (2002) stated that application of N along with Zn increased grain yield and grain-to-straw ratio in rice 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 a greater number of filled grains under reduced pH. Application of zinc along with N had synergistic effect on N and Zn uptake in rice.

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 (23.5 g) in rice and the minimum were recorded in control where no micronutrients were applied.

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 of rice.

Sankaran *et al.* (2001) reported significant increase in the grain yield of rice obtained with the application of 50 kg $ZnSO_4$ $ha^{-1}$ in red loam soil of Bhavanisagar.

Jena (1999) noticed significant increase in grain yield of rice with the soil application of 50 kg $ZnSO_4$ $ha^{-1}$ on clay loam soils of Bapatla.

Sharma *et al*. (1999) reported that soil application of 36 kg $ZnSO_4$ $ha^{-1}$ produced significantly higher effective tillers $m^{-2}$ in rice field on clay loam soils of Rajasthan. They also observed the highest grain yield of rice 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.

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

# CHAPTER III

# MATERIALS AND METHODS

The experiment was conducted to find out the effect of nitrogen and zinc scheduling on the performance of hybrid rice. This chapter deals with a brief description on experimental site, climate, soil, land preparation, layout, experimental design, intercultural operations, data recording and their analyses. The details of experimental materials and methods are described below:

## 3.1 Description of the experimental site

### 3.1.1 Experimental period

This research work was carried out during November, 2019 to May, 2020.

### 3.1.2 Experimental location

The experiment was carried out in the Boro season in the Field laboratory of the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh. The location of the site is 23°74/N latitude and 90°35/E longitude with an elevation of 8.2 meter from sea level. Experimental location presented in Appendix I.

### 3.1.3 Climatic condition

The geographical location of the experimental site was under the subtropical climate and its climatic conditions is characterized by three distinct seasons, namely winter season from the month of November to February, the pre-monsoon period or hot season from the month of March to April and monsoon period from the month of May to October (Edris *et al.*, 1979). During the experimental period the maximum temperature (36.8°C), highest relative humidity (87%) and highest rainfall (273 mm) was recorded for the month of May, 2020 whereas, the minimum temperature (14.60°C), minimum relative humidity (64%) and no rainfall was recorded for the month of January, 2020.

Details of the meteorological data of air temperature, relative humidity, rainfall and sunshine hour during study period has been presented in Appendix III.

### 3.1.4 Soil characteristics

The soil of the experimental field belonged to "The Madhapur Tract", AEZ-28 (FAO, 1988). Top soil was Silty Clay in texture, olive-grey with common fine to medium distinct dark yellowish-brown mottles. The experimental area having available irrigation and drainage system and situated above flood level. The soil having a texture of sandy loam organic matter 1.15% and composed of 26% sand, 43% silt and 31% clay. Details morphological, physical and chemical properties of the experimental field soil are presented in Appendix II.

## 3.2 Experimental details

### 3.2.1 Planting material

BRRI hybrid dhan2 was used in this study.

### 3.2.2 Treatment of the experiment

The experiment consisted of two factors:

**Factor A:** Nitrogen management (3 levels) as

i. $N_0$ – 0 kg $ha^{-1}$ (control),

ii. $N_1$ – 100 kg $ha^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and

iii. $N_2$ – 150 kg $ha^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]

**Factor B:** Zinc management (4 levels) as

i. $Zn_0$ - 0 kg $ha^{-1}$ (control),

ii. $Zn_1$ – 5 kg $ha^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)],

iii. $Zn_2$ – 10 kg $ha^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and

iv. $Zn_3$ – 10 kg $ha^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]

There were total 12 (3 × 4) combination as a whole *viz.*, $N_0Zn_0$, $N_0Zn_1$, $N_0Zn_2$, $N_0Zn_3$, $N_1Zn_0$, $N_1Zn_1$, $N_1Zn_2$, $N_1Zn_3$, $N_2Zn_0$, $N_2Zn_1$, $N_2Zn_2$ and $N_2Zn_3$.

### 3.2.3 Experimental design and layout

The 3×4 factorial experiment was laid out in Randomized Block Design (Factorial) with three replications. An area of 450.00 $m^2$ (25.00 × 18.00 m) was divided into 3 blocks. The whole experimental area was divided into three equal blocks, each representing a replication. The size of each unit plot was 2.00 m × 1.50 m.

## 3.3 Growing of crops

### 3.3.1 Seed collection and sprouting

Seeds of this variety were collected from Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh. Just 20 days ahead of the sowing of seeds in seed bed. For seedlings clean seeds were immersed in water in a bucket for 24 hours. The imbibed seeds were then taken out of water and kept in gunny bags. The seeds started sprouting after 48 hours which were suitable for sowing in the seed bed in 72 hours.

### 3.3.2 Raising of seedlings

The nursery bed was prepared by puddling with repeated ploughing followed by laddering. The sprouted seeds were sown on beds as uniformly as possible at 15$^{th}$ November, 2019. Irrigation was gently provided to the bed when needed. No fertilizer was used in the nursery bed.

### 3.3.3 Land preparation

The plot selected for conducting the experiment was opened in the 12$^{th}$ December, 2019 with a power tiller, and left exposed to the sun for a week. After one week the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain good puddle condition. Weeds and stubbles were removed. The experimental plot was partitioned into unit plots in accordance with the experimental design at 23th December, 2019. Organic and inorganic manures as indicated 3.3.4 were mixed with the soil of each unit plot.

### 3.3.4 Fertilizers and manure application

The fertilizers P, K, S and B in the form of TSP, MoP, Gypsum and borax, respectively. TSP, MoP, Gypsum and borax were applied @ 60, 40, 12 and 10 kg $ha^{-1}$ (BRRI, 2016). The doses of nitrogen and zinc were applied as per treatment through urea and $ZnSO_4.H_2O$ (monohydrate). The uniform (5 kg $ha^{-1}$) basal application of zinc [$ZnSO_4.H_2O$ (monohydrate)] was applied in all plots except zinc control plot. The entire amount of TSP, MoP, gypsum and borax were applied during final land preparation.

### 3.3.5 Transplanting of seedling

Seedlings were carefully uprooted from the nursery bed and transplanted on 26 December, 2019 in well puddled plot with spacing of 20 × 15 cm. One seedling was transplanted in each hill. After one week of transplanting all plots were checked for any missing hill, which was filled up with extra seedlings of the same source whenever required.

## 3.4 Intercultural operations

Intercultural operations were done to ensure normal growth of the crop. Plant protection measures were followed as and when necessary. The following intercultural operations were done.

### 3.4.1 Irrigation and drainage

In the early stages to establishment of the seedlings irrigation was provided to maintain a constant level of standing water up to 6 cm and then maintained the amount drying and wetting system throughout the entire vegetative phase. No water stress was encountered in reproductive and ripening phase. The plot was finally dried out at 15 days before harvesting.

### 3.4.2 Weeding

Weeding was done to keep the plots free from weeds, which ultimately ensured better growth and development of the seedlings. The weeds were uprooted carefully at 20 DAT (days after transplanting) and 40 DAT by mechanical means.

### 3.4.3 Insect and pest control

Furadan 5G were applied at 25 and 45 DAT in the plot. Leaf roller (*Chaphalocrosis medinalis*) was found and used Malathion 10 EC @ 1.12 L $ha^{-1}$ at 40 and 60 DAT using sprayer but no diseases infection was observed in the field.

## 3.5 Harvesting, threshing and cleaning

The crop was harvested at full maturity based on variety when 80–90% of the grains were turned into straw colour. The harvested crop was bundled separately, properly tagged and brought to threshing floor. The grains were dried, cleaned and weighed for individual plot. The weight was adjusted to 14% moisture content. Yields of rice grain and straw were recorded from each plot.

## 3.6 Recording of data

The following data were recorded during experimentation period:

i. Tiller number $hill^{-1}$,
ii. Leaf Area Index (LAI),
iii. Crop Growth Rate (CGR) (g running $m^{-1}$ $day^{-1}$),
iv. Panicle number $hill^{-1}$,
v. Panicle length (cm),
vi. Grain number $panicle^{-1}$,

vii. 1000-grain weight (g),

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

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

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

xi. Harvest Index (%)

## 3.7 Experimental measurements

A brief outline of the data recording procedure followed during the study is given below:

### 3.7.1 Tiller number $hill^{-1}$

Tiller number $hill^{-1}$ was recorded at 25, 55, 85 DAT and at harvest stage as the average of randomly selected 5 plants from the inner rows of each plot.

### 3.7.2 Leaf Area Index (LAI)

Green leaf area (LA) was measured by an automatic leaf area meter (Model: LI-3100, Li-COR, Lincoln, NE, USA) just after removal of leaves to avoid rolling and shrinkage and then transformed into leaf area index (LAI) according to Yoshida (1981).

### 3.7.3 Crop Growth rate (CGR)

CGR represents the increase of plant material per unit time per unit land area. It was measured by the following formula.

$$\text{CGR (g running m}^{-1}\text{ day}^{-1}) = \frac{W_2 - W_1}{T_2 - T_1}$$

Where,

$W_1$ = total dry matter (g) at time $T_1$ (day),

$W_2$ = Total dry matter (g) at time $T_2$ (day)

and $T_2 - T_1$ = time interval (days) between first and second harvests.

### 3.7.4 Panicle number hill$^{-1}$

The number of panicles was counted at maturity from randomly selected ten hills of each plot. The average value on this parameter was computed and expressed in terms of average panicle number hill$^{-1}$.

### 3.7.5 Panicle length

The length of panicles of tagged plants from each plot were measured with scale from the neck node to the tip of the panicle. Finally, the average value on the length of panicle was computed in centimetre.

### 3.7.6 Grain number panicle$^{-1}$

All panicles from the five tagged hills of each plot were threshed. Grain and sterile spikelets were separated by a seed sorter (Kiya Seisakusho LDT, model 1973, Tokyo, Japan). After separation, the grains were counted by an automatic counter (nagoga, model DC I-O, Japan) and then number of grains panicle$^{-1}$ was calculated.

### 3.7.7 1000-grain weight

A handful of grains was taken without any bias from the total grain produce of each plot, after threshing and cleaning. One thousand grains from each plot sample was counted and weighted on electronic balance and their weight was expressed in g per 1000 grains.

### 3.7.8 Grain yield

Crop was harvested according to maturity from each of the plot. After threshing, cleaning and sun drying, the grain weight was recorded and adjusted to 14% moisture content (MC) using the following formula.

$$\text{Grain yield at 14\% MC} = \frac{100-\text{Sample MC (\%)}}{100-14} \times \text{weight of the grains at harvest}$$

### 3.7.9 Straw yield

The fresh weight of straw of each hill (plot) was recorded and sample was oven dried at 70°C for 72 hours. The straw yield was calculated as follows.

Straw yield (dry weight basis) = Fresh weight of straw at harvest × Conversion Factor (CF)

Where,

$$\text{CF} = \frac{\text{Dry weight of straw sample}}{\text{Fresh weight of straw sample}}$$

### 3.7.10 Biological yield

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

Biological yield = Grain yield + Straw yield.

### 3.7.11 Harvest Index (HI)

Harvest index was calculated from the grain and straw yield of rice for each plot and expressed in percentage.

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

$$= \frac{\text{Grain yeild (t ha}^{-1}\text{)}}{\text{(Grain yield + Straw yield) (t ha}^{-1}\text{)}} \times 100$$

## 3.8 Statistical Analysis

The data obtained for different characters were statistically analysed to observe the significant difference among different treatments. The analysis of variance (ANOVA) of all the recorded parameters was performed using MSTAT-C software. The difference of the means value was separated by least significance difference (LSD) test at 5% level of probability (Gomez and Gomez, 1984).

# CHAPTER IV

# RESULTS AND DISCUSSION

The experiment was conducted to find out effect of nitrogen and zinc scheduling on the performance of hybrid rice. The results obtained from the study have been presented, discussed and compared in this chapter through table(s) and figures. The analysis of variance of data in respect of all the parameters has been shown in Appendix IV to IX. The results have been presented and discussed with the help of tables and graphs and possible interpretations given under the following headings. The analytical results have been presented in Table 1 through Table 9 and Figure 1 through Figure 6.

## 4.1 Tiller number hill$^{-1}$

### 4.1.1 Effect of nitrogen rate

Tiller number hill$^{-1}$ was significantly influenced by the nitrogen levels at all growth stages. Tiller number hill$^{-1}$ increased with age reaching a peak at 55 DAT and there after decline (Figure 1 and Appendix IV). As the nitrogen rate was increased from 0 kg N ha$^{-1}$ to 150 kg N ha$^{-1}$, the number of tillers increased significantly and at 25, 55, 85 DAT and at harvest stage, the maximum (15.48, 24.15, 18.55 and 17.16 tillers hill$^{-1}$, respectively) was observed with 150 kg N ha$^{-1}$ ($N_2$) and minimum (9.53, 16.51, 13.32 and 10.14 tillers hill$^{-1}$, respectively) with 0 kg N ha$^{-1}$ ($N_0$) treatment. Application of 150 kg N ha$^{-1}$ ($N_2$) produced maximum tiller hill$^{-1}$ and followed by 100 kg N ha$^{-1}$ ($N_1$) and control ($N_0$) irrespective of growth stage. The improvement in the formation of tillers with N application in the present experiment might be due to increase of nitrogen availability which enhanced tillering. Mirzeo and Reddy (1989) and Singh and Singh (1986) also reported that nitrogen produced highest number of tillers @ 87 kg N ha$^{-1}$. Kabir *et al.* (2009) and Masum *et al.* (2008) reported that highest number of tiller hill$^{-1}$ was found from full doses of Urea Super Granule (USG) @ 58 kg N ha$^{-1}$. Hasanuzzaman *et al.* (2009) reported that deep placement of USG @ 75 kg N ha$^{-1}$ showed highest number of tillers might be due to little loss of N from soil and slowly releasing process. Hamidullah *et al*. (2006) found that tiller number increased with increasing N and 120 and 160 kg N ha$^{-1}$ produced statistically similar tiller hill$^{-1}$. On the other hand, Peng *et al.* (1996) reported that N supply controlled the tiller production of rice plant unless other factors such as spacing or light became limiting.

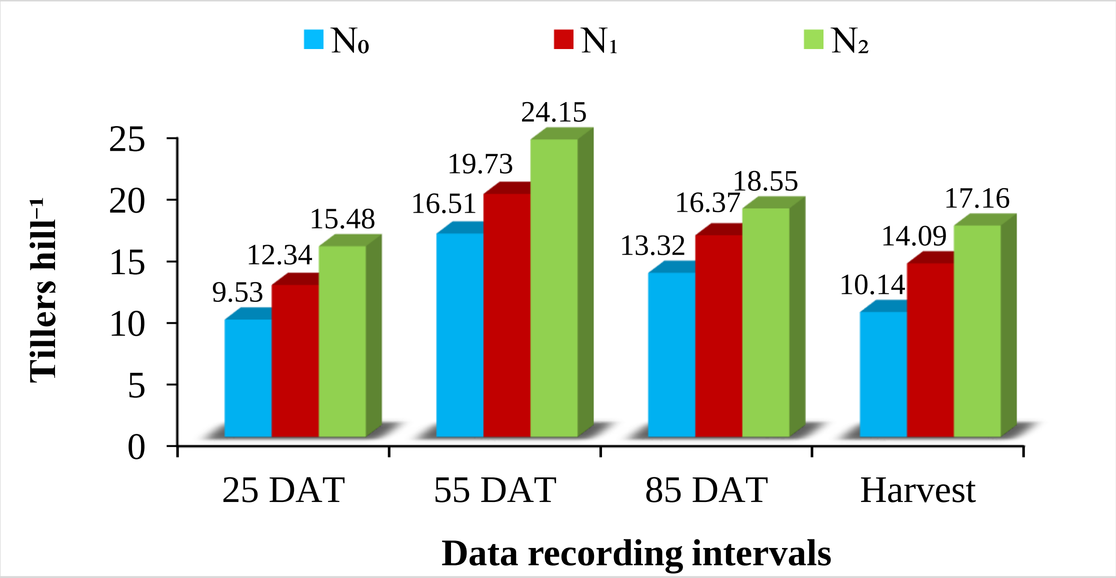


**Figure 1. Effect of nitrogen scheduling on the tillers number hill$^{-1}$ in BRRI hybrid dhan2 at different days after transplanting** (LSD value = 1.45, 2.03, 1.83 and 1.96 at 25, 55, 85 DAT and harvest, respectively)

**Note:** $N_0$ – 0 kg ha$^{-1}$ (control), $N_1$ – $N_1$ – 100 kg ha$^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and $N_2$ – 150 kg ha$^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]

### 4.1.2 Effect of zinc rate

Different rate of zinc varied in terms of number of tillers hill$^{-1}$ of hybrid rice at 25, 55, 85 DAT and harvest (Figure 2 and Appendix IV). At 25 and 55 DAT, the maximum (13.78 and 22.57 tillers hill$^{-1}$, respectively) was found from 10 kg Zn ha$^{-1}$ ($Zn_2$) which was statistically similar (13.06 and 21.50 tillers hill$^{-1}$, respectively) to $Zn_3$ treatment, while the minimum (10.83 and 16.64 tillers hill$^{-1}$, respectively) was recorded from 0 kg Zn ha$^{-1}$($Zn_0$). At 85 DAT, the maximum (18.68 tillers hill$^{-1}$) was found from 10 kg Zn ha$^{-1}$ ($Zn_2$) and the minimum (13.94 tillers hill$^{-1}$) was recorded from 0 kg Zn ha$^{-1}$($Zn_0$). At harvest stage, the maximum (16.42 tillers hill$^{-1}$) was found from 10 kg Zn ha$^{-1}$ ($Zn_2$) whereas, the minimum (12.22 tillers hill$^{-1}$) was recorded from 0 kg Zn ha$^{-1}$($Zn_0$) which was statistically identical to $Zn_1$ (13.01 tillers hill$^{-1}$) and $Zn_3$ (13.54 tillers hill$^{-1}$). Cheema *et al*. (2006) observed that number of tillers hill$^{-1}$ showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha$^{-1}$.

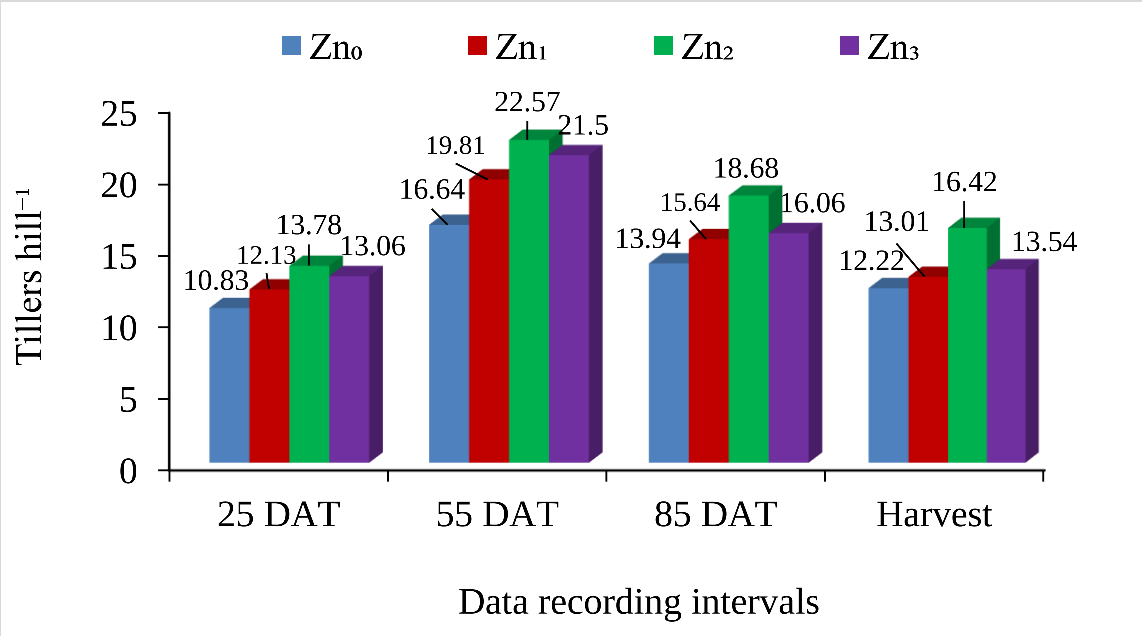


**Figure 2. Effect of zinc scheduling on the tiller number hill$^{-1}$ in BRRI hybrid dhan2 at different days after transplanting** (LSD value = 1.12, 1.58, 1.41 and 1.52 at 25, 55, 85 DAT and harvest, respectively)

**Note:** $Zn_0$ - 0 kg ha$^{-1}$ (control), $Zn_1$–5 kg ha$^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], $Zn_2$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and $Zn_3$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]

### 4.1.3 Interaction effect of nitrogen and zinc scheduling

The interaction effect of nitrogen and zinc scheduling showed significant influence on the tiller dynamic of the hybrid rice (Table 1 and appendix IV). At 25, 55, 85 DAT and at harvest, the maximum tiller number hill$^{-1}$ (17.13, 27.85, 21.55 and 19.78, respectively) was achieved by $N_2Zn_2$ (150 kg N ha$^{-1}$ and 10 kg Zn ha$^{-1}$) treatment combination which was statistically identical to $N_2Zn_3$ (16.24) at 25 DAT. At 25, 55, 85 DAT and at harvest, the minimum number of tillers hill$^{-1}$ (8.29, 13.65, 11.55 and 8.56, respectively) was found with $N_0Zn_0$ (0 kg N ha$^{-1}$ and 0 kg Zn ha$^{-1}$) which was statistically similar to $N_0Zn_1$ (9.28) and $N_0Zn_3$ (9.99) at 25 DAT; $N_0Zn_1$ (12.95) at 85 DAT and $N_0Zn_1$ (9.58) and $N_0Zn_3$ (9.98) at harvest stage.

**Table 1. Interaction effect of nitrogen and zinc scheduling on the tiller number hill$^{-1}$ in BRRI hybrid dhan2**

| Treatment combination | Tiller No. hill$^{-1}$ | | | |
|---|---|---|---|---|
| | **25 DAT** | **55 DAT** | **85 DAT** | **Harvest** |
| **$N_0Zn_0$** | 8.29 f | 13.65 f | 11.55 f | 8.56 d |
| **$N_0Zn_1$** | 9.28 f | 16.25 e | 12.95 ef | 9.58 d |
| **$N_0Zn_2$** | 10.54 e | 17.11 e | 15.47 cd | 12.44 c |
| **$N_0Zn_3$** | 9.99 ef | 19.04 d | 13.30 e | 9.98 d |
| **$N_1Zn_0$** | 10.74 e | 16.31 e | 14.19 de | 12.53 c |
| **$N_1Zn_1$** | 12.02 d | 19.41 d | 15.92 c | 13.13 c |
| **$N_1Zn_2$** | 13.66 c | 22.75 c | 19.02 b | 17.04 b |
| **$N_1Zn_3$** | 12.95 cd | 20.44 d | 16.35 c | 13.67 c |
| **$N_2Zn_0$** | 13.47 c | 19.96 d | 16.08 c | 15.57 b |
| **$N_2Zn_1$** | 15.08 b | 23.76 bc | 18.04 b | 16.31 b |
| **$N_2Zn_2$** | 17.13 a | 27.85 a | 21.55 a | 19.78 a |
| **$N_2Zn_3$** | 16.24 a | 25.02 b | 18.53 b | 16.98 b |
| **LSD (0.05)** | **1.12** | **1.58** | **1.41** | **1.52** |
| **CV (%)** | **9.75** | **8.34** | **4.98** | **9.27** |

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

**Note:** $N_0$ – 0 kg ha$^{-1}$ (control), $N_1$ – $N_1$ – 100 kg ha$^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and $N_2$ – 150 kg ha$^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]
$Zn_0$ - 0 kg ha$^{-1}$ (control), $Zn_1$–5 kg ha$^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], $Zn_2$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and $Zn_3$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]

## 4.2 Leaf Area Index (LAI)

### 4.2.1 Effect of nitrogen rate

Leaf area index (LAI) or the surface area of green leaves produced by rice plants unit area$^{-1}$ of land was taken as an index of leaf area development. The leaf area of plant is one of the major determinants of its growth. LAI was significantly influenced by nitrogen rate at different growth stages (Figure 3 and Appendix V). Nitrogen level 150 kg N ha$^{-1}$ ($N_2$), maintained the superior LAI as compared to other treatment at all the growth stages of observations. The highest LAI (0.94, 4.90 and 5.49, respectively) was found at 25, 55 and 85 DAT due to the effect of 150 kg N ha$^{-1}$ ($N_2$) whereas, the lowest LAI (0.48, 1.78 and 2.87, respectively) was found at 25, 55 and 85 DAT due to the effect of 0 kg N ha$^{-1}$ ($N_0$). Masum *et al.* (2008) reported that LAI was significantly higher in USG receiving plants than urea. Gorgy *et al*. (2009) observed higher LAI (7.09) with application of 165 kg N ha$^{-1}$ as three equal splits and Hamidullah *et al*. (2006) found maximum LAI with 160 kg N ha$^{-1}$. Ali (2005) and Miah *et al.* (2004) reported that LAI was significantly higher in USG receiving plants than urea.

### 4.2.2 Effect of zinc rate

Significant variation was observed in terms of leaf area index (LAI) at different growth stages of hybrid rice influenced by different zinc rate (Figure 4 and Appendix V). It was observed that the highest LAI (0.75, 3.68 and 4.42 at 25, 55 and 85 DAT, respectively) was obtained from the treatment $Zn_2$ (10 kg Zn ha$^{-1}$) which was statistically identical with $Zn_3$ (0.75, 3.63 and 4.41 at 25, 55 and 85 DAT, respectively) whereas, the lowest LAI (0.52, 2.95 and 3.75, respectively) at 25, 55 and 85 DAT was found from the treatment $Zn_0$ (0 kg Zn ha$^{-1}$). Similar result also reported by Hussain and Yasin (2004) also concluded that application of Zn as foliar spraying in rice is highly attractive and produced higher LAI than control treatment.

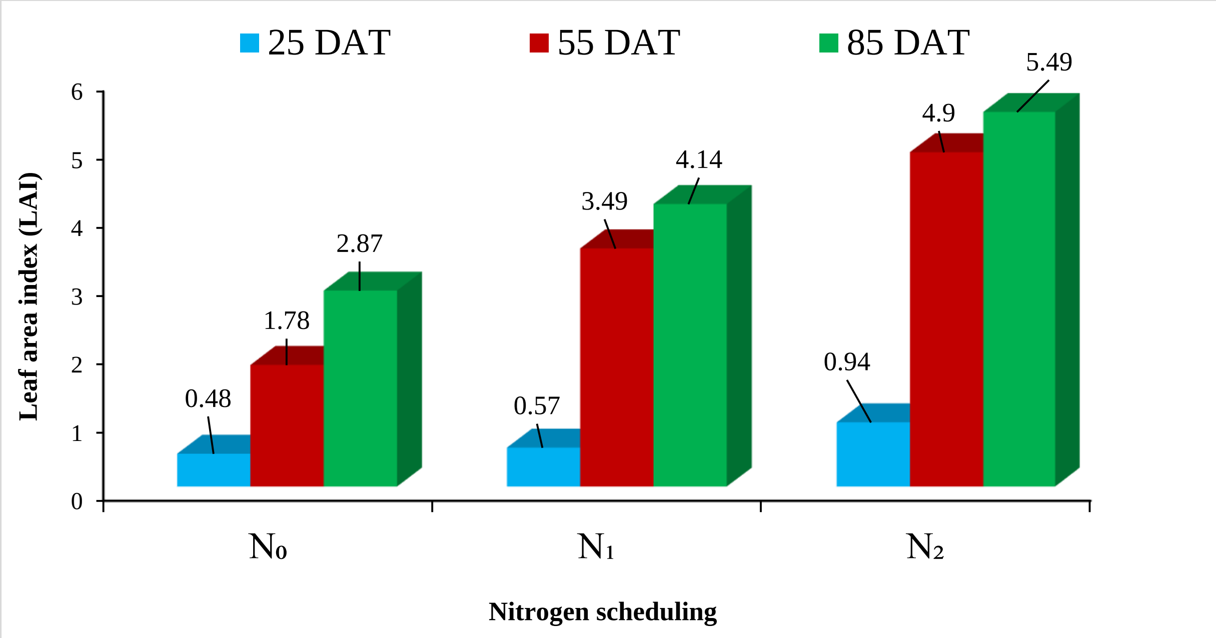


**Figure 3. Effect of nitrogen scheduling on the leaf area index (LAI) in BRRI hybrid dhan2 at different days after transplanting** (LSD value = 0.08, 0.22 and 0.24 at 25, 55 and 85 DAT, respectively)

**Note:** $N_0$ – 0 kg ha$^{-1}$ (control), $N_1$ – $N_1$ – 100 kg ha$^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and $N_2$ – 150 kg ha$^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]

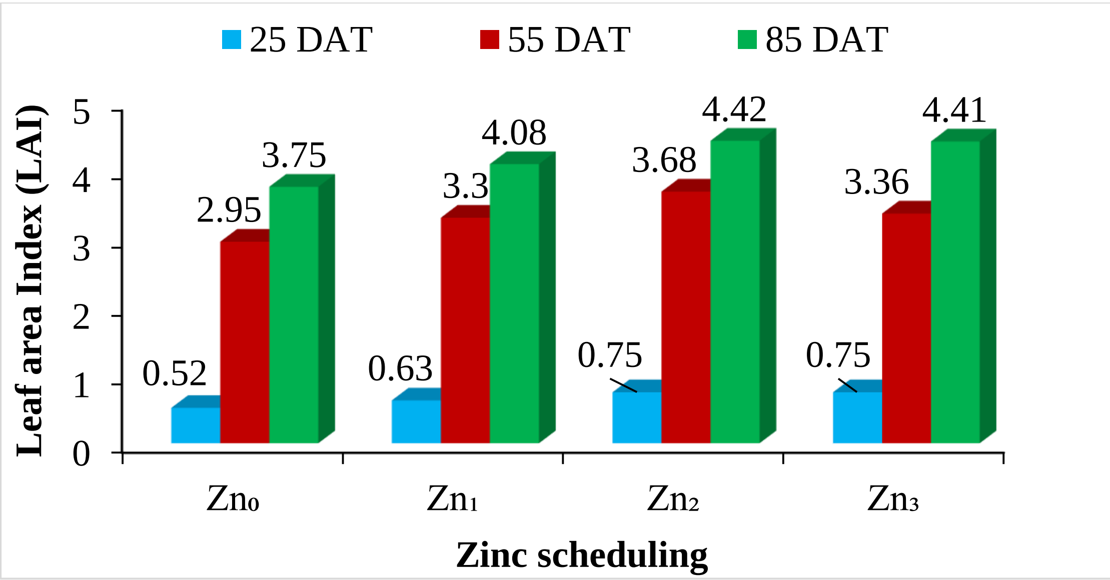


**Figure 4. Effect of zinc scheduling on the leaf area index (LAI) in BRRI hybrid dhan2 at different days after transplanting** (LSD value = 0.06, 0.28 and 0.31 at 25, 55 and 85 DAT, respectively)

**Note:** $Zn_0$ **-** 0 kg ha$^{-1}$ (control), $Zn_1$–5 kg ha$^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], $Zn_2$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and $Zn_3$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]

**Table 2. Interaction effect of nitrogen and zinc scheduling on the leaf area index (LAI) in BRRI hybrid dhan2**

| Treatment combination | Leaf area index | | |
|---|---|---|---|
| | **25 DAT** | **55 DAT** | **85 DAT** |
| **$N_0Zn_0$** | 0.38 g | 1.55 h | 2.58 h |
| **$N_0Zn_1$** | 0.45 f | 1.73 gh | 2.81 h |
| **$N_0Zn_2$** | 0.54 e | 1.93 g | 3.04 g |
| **$N_0Zn_3$** | 0.54 e | 1.91 g | 3.04 g |
| **$N_1Zn_0$** | 0.45 f | 3.04 f | 3.73 f |
| **$N_1Zn_1$** | 0.54 e | 3.40 e | 4.05 e |
| **$N_1Zn_2$** | 0.65 d | 3.79 d | 4.39 d |
| **$N_1Zn_3$** | 0.65 d | 3.74 d | 4.38 d |
| **$N_2Zn_0$** | 0.74 c | 4.27 c | 4.95 c |
| **$N_2Zn_1$** | 0.89 b | 4.77 b | 5.37 b |
| **$N_2Zn_2$** | 1.07 a | 5.32 a | 5.83 a |
| **$N_2Zn_3$** | 1.07 a | 5.24 a | 5.81 a |
| **LSD (0.05)** | **0.06** | **0.28** | **0.31** |
| **CV (%)** | **10.82** | **11.24** | **9.37** |

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

**Note:** $N_0$ – 0 kg $ha^{-1}$ (control), $N_1$ – $N_1$ – 100 kg $ha^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and $N_2$ – 150 kg $ha^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]
$Zn_0$ - 0 kg $ha^{-1}$ (control), $Zn_1$–5 kg $ha^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], $Zn_2$ – 10 kg $ha^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and $Zn_3$ – 10 kg $ha^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]

### 4.2.3 Interaction effect of nitrogen and zinc scheduling

The interaction effect of nitrogen and zinc scheduling showed significant influence on the leaf area index (LAI) of the hybrid rice (Table 2 and appendix V). At 25, 55 and 85 DAT, the highest LAI (1.07, 5.32 and 5.83, respectively) was observed with $N_2Zn_2$ (150 kg N $ha^{-1}$ and 10 kg Zn $ha^{-1}$) which was statistically similar with $N_2Zn_3$ (1.07, 5.24 and 5.81, respectively). On the other hand, at 25, 55 and 85 DAT, the lowest LAI (0.38, 1.55 and 2.58, respectively) was found by $N_0Zn_0$ (0 kg N $ha^{-1}$ and 0 kg Zn $ha^{-1}$) which was statistically similar with $N_0Zn_1$ (1.73 and 2.81 at 55 and 85 DAT, respectively).

## 4.3 Crop Growth Rate (CGR)

### 4.3.1 Effect of nitrogen rate

Crop growth rate (CGR) was significantly influenced by nitrogen rate at different growth stages (Figure 5 and Appendix VI). Critical appraised of the data showed that the maximum crop growth rate was recorded with 150 kg N $ha^{-1}$ ($N_2$), at 25, 55 and 85 DAT. The maximum CGR (0.56, 4.21 and 5.19 g running $m^{-1}$ $day^{-1}$, respectively) was recorded with 150 kg N $ha^{-1}$ ($N_2$). On the other hand, the minimum CGR (0.26, 1.08 and 2.55 g running $m^{-1}$ $day^{-1}$, respectively) was found at 25, 55 and 85 DAT due to the effect of 0 kg N $ha^{-1}$ ($N_0$). Similar results were also reported by Azarpour *et al.* (2014).

### 4.3.2 Effect of zinc rate

Significant variation was observed in terms of crop growth rate (CGR) at different growth stages of hybrid rice influenced by different zinc rate except 25 DAT (Figure 6 and Appendix VI). At 25 DAT, numerically maximum CGR (0.43 g running $m^{-1}$ $day^{-1}$) was recorded with $Zn_2$ (10 kg Zn $ha^{-1}$) and minimum (0.36 g running $m^{-1}$ $day^{-1}$) was recorded with $Zn_0$ (0 kg Zn $ha^{-1}$). It was observed that the maximum CGR (3.41 and 4.68 g running $m^{-1}$ $day^{-1}$ at 55 and 85 DAT, respectively) was obtained from the treatment $Zn_2$ (10 kg Zn $ha^{-1}$) which was statistically identical with $Zn_3$ (4.50 g running $m^{-1}$ $day^{-1}$ at 85 DAT) whereas, the minimum CGR (1.75 and 3.12 g running $m^{-1}$ $day^{-1}$, respectively) at 55 and 85 DAT was found from the treatment $Zn_0$ (0 kg Zn $ha^{-1}$). Similar results were also reported by Boonchuay *et al.* (2013b); Muthukumararaja and Sriramachandrasekharan (2012).

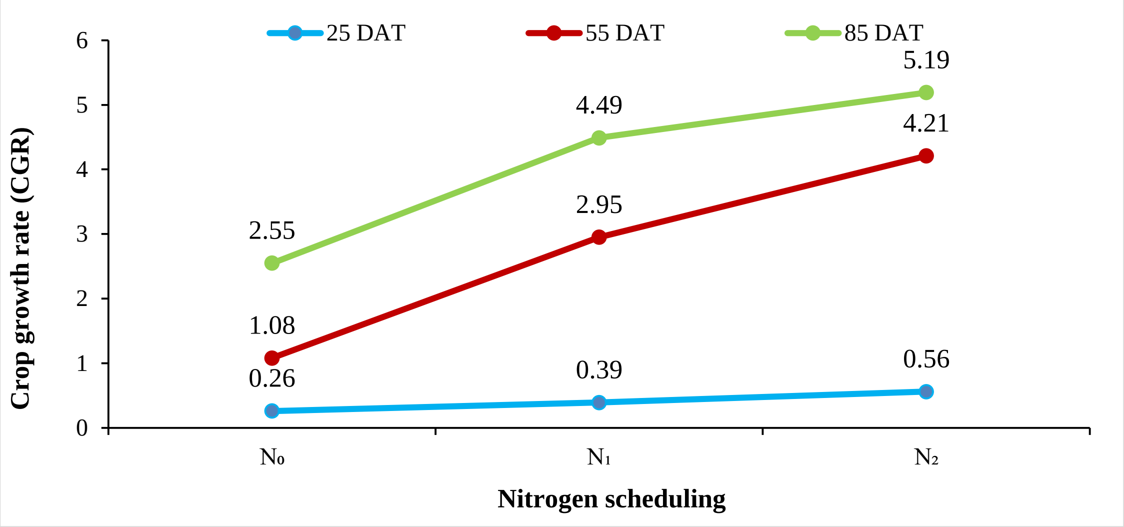


**Figure 5. Effect of nitrogen scheduling on the crop growth rate (CGR) in BRRI hybrid dhan2 at different days after transplanting** (LSD value = 0.07. 0.29 and 0.49 at 25, 55 and 85 DAT, respectively)

**Note:** $N_0$ – 0 kg ha$^{-1}$ (control), $N_1$ – $N_1$ – 100 kg ha$^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and $N_2$ – 150 kg ha$^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]

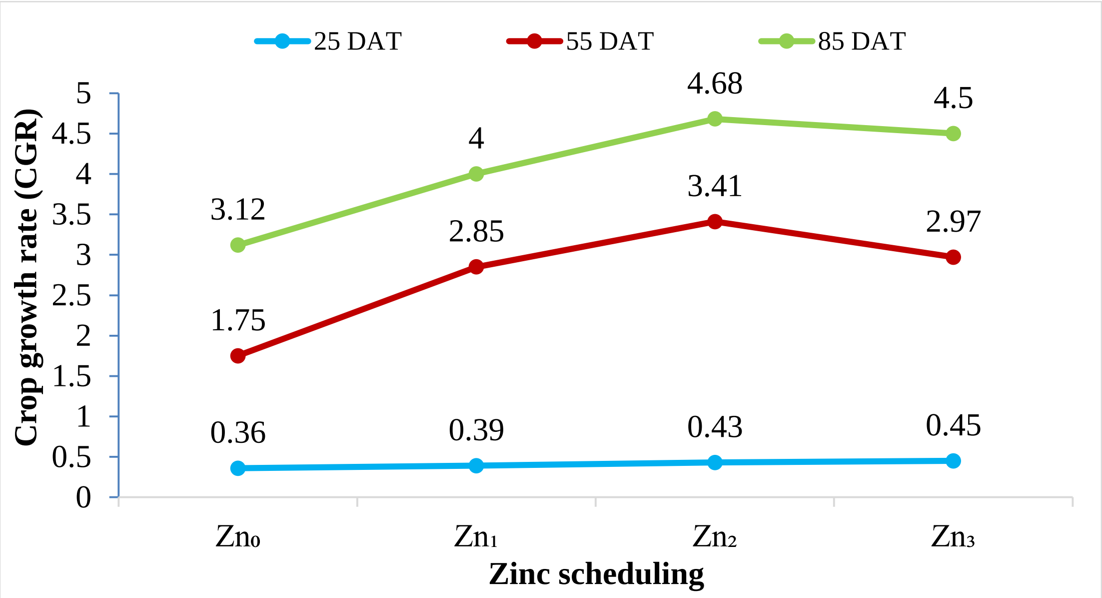


**Figure 6. Effect of zinc scheduling on the crop growth rate (CGR) in BRRI hybrid dhan2 at different days after transplanting** (LSD value = NS, 0.21 and 0.38 at 25, 55 and 85 DAT, respectively)

**Note:** $Zn_0$ - 0 kg ha$^{-1}$ (control), $Zn_1$–5 kg ha$^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], $Zn_2$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and $Zn_3$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]

**Table 3. Interaction effect of nitrogen and zinc scheduling on the crop growth rate (CGR) in BRRI hybrid dhan2**

| Treatment combination | Crop growth rate (g running $m^{-1}$ $day^{-1}$) | | |
|---|---|---|---|
| | **25 DAT** | **55 DAT** | **85 DAT** |
| **$N_0Zn_0$** | 0.23 e | 0.69 h | 1.95 g |
| **$N_0Zn_1$** | 0.24 e | 1.12 g | 2.51 f |
| **$N_0Zn_2$** | 0.27 e | 1.34 g | 2.93 f |
| **$N_0Zn_3$** | 0.28 e | 1.17 g | 2.82 f |
| **$N_1Zn_0$** | 0.35 de | 1.88 f | 3.43 e |
| **$N_1Zn_1$** | 0.38 d | 3.06 d | 4.41 d |
| **$N_1Zn_2$** | 0.42 cd | 3.66 c | 5.16 c |
| **$N_1Zn_3$** | 0.44 c | 3.18 d | 4.96 c |
| **$N_2Zn_0$** | 0.49 c | 2.68 e | 3.97 d |
| **$N_2Zn_1$** | 0.54 bc | 4.37 b | 5.09 c |
| **$N_2Zn_2$** | 0.59 ab | 5.23 a | 5.96 a |
| **$N_2Zn_3$** | 0.62 a | 4.55 b | 5.73 b |
| **LSD (0.05)** | **0.07** | **0.29** | **0.49** |
| **CV (%)** | **13.78** | **11.82** | **10.27** |

**In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability**

**Note:** $N_0$ – 0 kg $ha^{-1}$ (control), $N_1$ – $N_1$ – 100 kg $ha^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and $N_2$ – 150 kg $ha^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]

$Zn_0$ - 0 kg $ha^{-1}$ (control), $Zn_1$–5 kg $ha^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], $Zn_2$ – 10 kg $ha^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and $Zn_3$ – 10 kg $ha^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]

### 4.3.3 Interaction effect of nitrogen and zinc scheduling

The interaction effect of nitrogen and zinc scheduling showed significant influence on the crop growth rate (CGR) of the hybrid rice (Table 3 and Appendix V). At 25 DAT, the maximum CGR (0.62 g running $m^{-1}$ $day^{-1}$) was observed with $N_2Zn_3$ (150 kg N $ha^{-1}$ and 10 kg Zn $ha^{-1}$) which was statistically similar with $N_2Zn_2$ (0.59 g running $m^{-1}$ $day^{-1}$) whereas, the minimum (0.23 g running $m^{-1}$ $day^{-1}$) was observed with $N_0Zn_0$ (0 kg N $ha^{-1}$ and 0 kg Zn $ha^{-1}$) which was statistically identical with $N_0Zn_1$ (0.24 g running $m^{-1}$ $day^{-1}$), $N_0Zn_2$ (0.27 g running $m^{-1}$ $day^{-1}$), $N_0Zn_3$ (0.28 g running $m^{-1}$ $day^{-1}$) and $N_1Zn_0$ (0.35 g running $m^{-1}$ $day^{-1}$). At 55 and 85 DAT, the maximum CGR (5.23 and 5.96 g running $m^{-1}$ $day^{-1}$, respectively) was found by $N_2Zn_2$ (150 kg N $ha^{-1}$ and 10 kg Zn $ha^{-1}$) whereas, the minimum CGR (0.69 and 1.95 g running $m^{-1}$ $day^{-1}$, respectively) was found by $N_0Zn_0$ (0 kg N $ha^{-1}$ and 0 kg Zn $ha^{-1}$) treatment.

## 4.4 Panicle number hill$^{-1}$

### 4.4.1 Effect of nitrogen rate

The application of nitrogen rate significantly increased the panicle number hill$^{-1}$ (Table 4 and appendix VII). The highest panicle number hill$^{-1}$ (14.25) was found from $N_2$ (150 kg N $ha^{-1}$) whereas, the lowest (7.50) was obtained from $N_0$ (0 kg N $ha^{-1}$). Application of 150 kg N $ha^{-1}$ produced 47.39 % higher panicles hill$^{-1}$ than control treatment. This might be due to the fact that the number of tillers at this level of nitrogen was so high that even after mortality, it remained significantly higher than that of other levels of nitrogen and this consequently led to a greater number of panicles bearing tillers and panicle at this type of nitrogen management. Similar findings also reported by Puteh and Mondal (2014).

### 4.4.2 Effect of zinc rate

Panicle number hill$^{-1}$ of hybrid rice showed statistically significant differences due to different rate of zinc (Table 5 and Appendix VII). The highest panicle number hill$^{-1}$ (13.33) was found from $Zn_2$ (10 kg Zn $ha^{-1}$) treatment, while the lowest number (9.78) was recorded from $Zn_0$ (0 kg Zn $ha^{-1}$) treatment which was statistically similar (10.28) to $Zn_1$ and followed (10.87) by $Zn_3$ treatment. These may be due to contribution of zinc in plant growth. The similar kind of result was recorded by Yin *et al.* (2016).

### 4.4.3 Interaction effect of nitrogen and zinc scheduling

Interaction effect of nitrogen and zinc scheduling was found significant on panicle number hill$^{-1}$ of hybrid rice (Table 6 and appendix VII). The highest panicle number hill$^{-1}$ (17.17) was found from the combination of $N_2Zn_2$ (150 kg N ha$^{-1}$ and 10 kg Zn ha$^{-1}$). On the other hand, the lowest panicle number hill$^{-1}$ (6.63) was found in $N_0Zn_0$which was statistically identical with $N_0Zn_1$ (6.97) and $N_0Zn_3$ (7.37).

## 4.5 Panicle length

### 4.5.1 Effect of nitrogen rate

Panicle length was influenced significantly by nitrogen application (Table 4 and Appendix VII). The longest panicle (25.73 cm) was found at higher rate of fertilizer dose (150 kg N ha$^{-1}$) which was statistically identical with 100 kg N ha$^{-1}$ (25.37 cm). The shortest panicle (22.53 cm) was observed at the control (0 kg N ha$^{-1}$) treatment. Panicle length was increased with the increasing level of fertilizer. Rafey *et al*. (1989) also observed that increasing fertilizer levels increased panicle length. The result was corroborated with the findings of Hasanuzzaman *et al*. (2009) who found that USG @ 75 kg N ha$^{-1}$ produced the longest panicle.

### 4.5.2 Effect of zinc rate

Non-significant differences were noticed in respect of panicle length in rice due to different rate of Zn application (Table 5 and Appendix VII). Among the rate of Zn application, the numerically longest panicle (25.30 cm) was recorded in 10 kg Zn ha$^{-1}$ ($Zn_3$) and the numerically shortest panicle (24.35) obtained from 5 kg Zn ha$^{-1}$ ($Zn_1$) treatment. The increase of panicle length could not be ascribed to the rate 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.

### 4.5.3 Interaction effect of nitrogen and zinc scheduling

Panicle length was significantly influenced by the interaction effect of different rate of nitrogen and zinc in hybrid rice (Table 6 and Appendix VII). The longest panicle (26.17 cm) was recorded in 150 kg N $ha^{-1}$ and 10 kg Zn $ha^{-1}$ ($N_2Zn_3$) which was statistically similar with $N_2Zn_2$ (25.98 cm), $N_1Zn_3$ (25.80 cm), $N_1Zn_2$ (25.62 cm), $N_2Zn_0$ (25.57 cm), $N_2Zn_1$ (25.18 cm), $N_1Zn_0$ (25.22 cm) and $N_1Zn_1$ (24.83 cm). On the other hand, the shortest panicle length (23.03 cm) was obtained from no nitrogen and zinc application ($N_0Zn_1$) which was statistically similar with $N_0Zn_0$ (23.39 cm), $N_0Zn_2$ (23.76 cm) and $N_0Zn_3$ (23.93 cm).

**Table 4. Effect of nitrogen scheduling on the yield components in BRRI hybrid dhan2**

| Nitrogen scheduling | Panicle number $hill^{-1}$ | Panicle length (cm) | Number of grain $panicle^{-1}$ | 1000-grain weight (g) |
|---|---|---|---|---|
| **$N_0$** | 7.50 c | 23.53 b | 84.95 c | 21.33 c |
| **$N_1$** | 11.43 b | 25.37 a | 100.70 b | 23.75 b |
| **$N_2$** | 14.25 a | 25.73 a | 111.95 a | 25.50 a |
| **LSD $_{(0.05)}$** | **1.57** | **1.47** | **8.85** | **1.55** |
| **CV (%)** | **7.82** | **4.92** | **6.54** | **4.36** |

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

**Note:** $N_0$ – 0 kg $ha^{-1}$ (control), $N_1$ – $N_1$ – 100 kg $ha^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and $N_2$ – 150 kg $ha^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]

## 4.6 Grain number $panicle^{-1}$

### 4.6.1 Effect of nitrogen rate

Grain number $panicle^{-1}$ was significantly influenced by nitrogen application (Table 4 and Appendix VII). The highest grain number $panicle^{-1}$ (111.95) was found from $N_2$ (150 kg N $ha^{-1}$) which was followed by 100 kg N $ha^{-1}$ (100.70). The lowest grain number $panicle^{-1}$ (84.95) was obtained from $N_0$ (0 kg N $ha^{-1}$) treatment. $N_2$ (150 kg N $ha^{-1}$) produced 37.86% higher grain number $panicle^{-1}$

than control treatment. BRRI (2006) reported that grains panicle$^{-1}$ increased with higher N rates up to 120 kg N ha$^{-1}$. Awan *et al.* (2011) reported that maximum grain number panicle$^{-1}$ was produced in case of 156 kg N ha$^{-1}$. Gorgy *et al.* (2009) found maximum grain number panicle$^{-1}$ with three equal split of 165 kg N ha$^{-1}$.

### 4.6.2 Effect of zinc rate

Grain number panicle$^{-1}$ affected significantly due to rate of Zn application in hybrid rice (Table 5 and Appendix VII) which indicated that zinc fertilization by all the three rates increased the grain number panicle$^{-1}$ significantly over no Zn application. The highest value of grains panicle$^{-1}$ (106.11) was recorded in 10 kg Zn ha$^{-1}$ ($Zn_2$) treatment which was statistically identical with $Zn_3$ (104.31) whereas, the lowest (89.01) was recorded in 0 kg Zn ha$^{-1}$ ($Zn_0$) treatment. This might be due to higher zinc supply from $ZnSO_4.H_2O$ 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*. (2011a).

### 4.6.3 Interaction effect of nitrogen and zinc scheduling

Significant variation was found by combined effect nitrogen and zinc in case of grain number panicle$^{-1}$ of hybrid rice (Table 6 and Appendix VII). Result revealed the highest grains panicle$^{-1}$ (119.74) was recorded from the combination treatment of $N_2Zn_2$ which was statistically similar to $N_2Zn_3$ (117.71). On the other hand, the lowest grain number panicle$^{-1}$ (76.22) were achieved by the combination treatment of $N_0Zn_0$ which was statistically similar to $N_0Zn_1$ (83.39).

**Table 5. Effect of zinc scheduling on the yield components in BRRI hybrid dhan2**

| Zinc scheduling | Panicle number hill$^{-1}$ | Panicle length (cm) | Number of grain panicle$^{-1}$ | 1000-grain weight (g) |
|---|---|---|---|---|
| **$Zn_0$** | 9.78 b | 24.73 | 89.01 c | 22.60 b |
| **$Zn_1$** | 10.28 b | 24.35 | 97.37 b | 23.67 ab |
| **$Zn_2$** | 13.33 a | 25.12 | 106.11 a | 24.38 a |
| **$Zn_3$** | 10.87 b | 25.30 | 104.31 a | 23.44 ab |
| **LSD (0.05)** | **1.21** | **NS** | **6.85** | **1.55** |
| **CV (%)** | **7.82** | **4.92** | **6.54** | **4.36** |

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

**Note:** $Zn_0$ - 0 kg ha$^{-1}$ (control), $Zn_1$–5 kg ha$^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], $Zn_2$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and $Zn_3$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]

## 4.7 1000-grain weight

### 4.7.1 Effect of nitrogen rate

The weight of 1000 grains were significantly influenced by the different rate of nitrogen (Table 4 and Appendix VII). The maximum 1000-grain weight (25.50 g) was obtained from highest rate of nitrogen (150 kg N ha$^{-1}$) and the minimum (21.33 g) was obtained from control no nitrogen application (0 kg N ha$^{-1}$). The results were in consistent with the report of Chandrasharan and Salam (1995). Hasanuzzaman *et al*. (2009) reported that application of USG @ 75 kg N ha$^{-1}$ gave the highest thousand grain weight. Gorgy *et al*. (2009) reported that application of 165 kg N ha$^{-1}$ with three equal splits gave maximum value of thousand grain weight. Awan *et al*. (2011) found application of 156 kg N ha$^{-1}$ gave maximum 1000 grain. But the result did not agree with the findings of Ibrahiem *et al*. (2004) that with the increasing levels of nitrogen had no significant effect on 1000 grain weight. Islam *et al*. (2008a) reported weight of

1000 grain weight was not significantly influenced by N level as it is mostly governed by genetic makeup of the variety.

**Table 6. Interaction effect of nitrogen and zinc scheduling on the yield components in BRRI hybrid dhan2**

| Treatment combination | Panicle number $hill^{-1}$ | Panicle length (cm) | Number of grain $panicle^{-1}$ | 1000-grain weight (g) |
|---|---|---|---|---|
| **$N_0Zn_0$** | 6.63 f | 23.39 de | 76.22 f | 20.49 f |
| **$N_0Zn_1$** | 6.97 f | 23.03 e | 83.39 ef | 21.46 ef |
| **$N_0Zn_2$** | 9.04 e | 23.76 c-e | 90.87de | 22.11 d-f |
| **$N_0Zn_3$** | 7.37 f | 23.93 b-e | 89.32 e | 21.25 d-f |
| **$N_1Zn_0$** | 10.11 de | 25.22 ab | 90.35 de | 22.81 de |
| **$N_1Zn_1$** | 10.62 d | 24.83 a-d | 98.84 d | 23.90 cd |
| **$N_1Zn_2$** | 13.78 bc | 25.62 a | 107.71 bc | 24.61 bc |
| **$N_1Zn_3$** | 11.23 d | 25.80 a | 105.88 b-d | 23.66 cd |
| **$N_2Zn_0$** | 12.60 c | 25.57 a | 100.45 cd | 24.50 bc |
| **$N_2Zn_1$** | 13.24 bc | 25.18 a-c | 109.88 b | 25.66 ab |
| **$N_2Zn_2$** | 17.17 a | 25.98 a | 119.74 a | 26.43 a |
| **$N_2Zn_3$** | 14.00 b | 26.17 a | 117.71 ab | 25.41 ab |
| **LSD $_{(0.05)}$** | 1.21 | 1.47 | 8.85 | 1.40 |
| **CV (%)** | 7.82 | 4.92 | 6.54 | 4.36 |

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

**Note:** $N_0$ – 0 kg $ha^{-1}$ (control), $N_1$ – $N_1$ – 100 kg $ha^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and $N_2$ – 150 kg $ha^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]

$Zn_0$ - 0 kg $ha^{-1}$ (control), $Zn_1$–5 kg $ha^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], $Zn_2$ – 10 kg $ha^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and $Zn_3$ – 10 kg $ha^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]

### 4.7.2 Effect of zinc rate

Statistically significant variation was recorded for weight of 1000-grains due to different rate of zinc application (Table 5 and Appendix VII). The maximum weight of 1000-grains (24.38 g) was recorded from $Zn_2$ (10 kg Zn $ha^{-1}$) which was statistically similar with $Zn_1$ (23.67 g) and $Zn_3$ (23.44 g) and the lowest weight (22.60 g) was recorded to control (0 kg Zn $ha^{-1}$) treatment. Ullah *et al*. (2001) found the highest 1000-grain weight (28.70 g) from 20 kg zinc sulfate $ha^{-1}$. 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 Abid *et al*. (2011).

### 4.7.3 Interaction effect of nitrogen and zinc scheduling

Interaction effect of different rate of nitrogen and zinc application significantly influenced on 1000-seed weight (Table 6 and Appendix VII). Results indicated that the maximum 1000-seed weight (26.43 g) was with interaction of $N_2Zn_2$ which was statistically similar to $N_2Zn_1$ (25.66 g) and $N_2Zn_3$ (25.41 g). On the other hand, the minimum result was obtained from $N_0Zn_0$ (20.49 g) which was statistically similar to $N_0Zn_3$ (21.25 g), $N_0Zn_1$ (21.46 g) and $N_0Zn_2$ (22.11 g).

## 4.8 Grain yield

### 4.8.1 Effect of nitrogen rate

Grain yield was significantly influenced by different rate of nitrogen in hybrid rice (Table 7 and Appendix VIII). Critical observation of the data showed that nitrogen rate positively increased the grain yield. Significantly higher grain yield (7.11 t $ha^{-1}$) with 150 kg N $ha^{-1}$ ($N_2$), which was significantly higher remaining treatments. However, the grain yield of 5.01 t $ha^{-1}$ was recorded with application of 100 kg N $ha^{-1}$ (N1) respectively, over control (2.97 t $ha^{-1}$). These results agree with those obtained by Hussain and Sharma (1991) who observed that the grain yield increased significantly up to the application of higher rate of fertilizer and thereafter declined. The increment of grain yields up to highest rate of fertilizer (120 kg urea $ha^{-1}$) application might be due to supply of available nutrients to the crop. Further, the increased level of fertilizer decreased grain yield significantly due to excessive plant growth and crop lodging. Placement of nitrogen fertilizer in the form of USG @ 75 kg N $ha^{-1}$ in the present experiment produced the highest number of effective tillers $hill^{-1}$, filled grains $panicle^{-1}$ which ultimately gave higher grain yield. BRRI (2009) reported that highest grain yield was recorded when N applied as 100 kg N $ha^{-1}$. BRRI (2006) reported that cultivation of hybrid rice in Boro required 120 kg N $ha^{-1}$. Similar results were reported by Hasanuzzaman *et al.* (2009), Masum *et al.* (2008), Mishra *et al.* (2000) and Raju *et al.* (1987) who observed nitrogen produced the highest grain yield and proved significantly superior to other sources.

### 4.8.2 Effect of zinc rate

Grain yield was significantly influenced by different rate of zinc in hybrid rice (Appendix VIII). Critical appraisal of data (Table 8) showed that grain yield of crop was influenced by zinc application at different stages. Among treatments, the highest grain yield (6.32 t $ha^{-1}$) was obtained with $Zn_2$, which was significantly higher than all remaining treatments. However, the grain yields of 5.84 t $ha^{-1}$ and 5.05 t $ha^{-1}$was obtained with $Zn_3$ and $Zn_1$, respectively that was significant higher control (2.95 t $ha^{-1}$). Cheema *et al*. (2006) observed that paddy yield showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg $ha^{-1}$. Zinc deficiency is the most widespread micronutrient disorder in lowland rice and application of zinc along with NPK fertilizer increases the grain yield dramatically in most cases (Chaudhary *et al*., 2007; Muthukumararaja and Sriramachandrasekharan, 2012). Khan *et al.* (2007) reported that increasing levels of Zn significantly influenced grain yield of rice.

### 4.8.3 Interaction effect of nitrogen and zinc scheduling

The interaction effect of different rate of nitrogen and zinc exerted significant influence on the grain yield of hybrid rice (Table 9 and Appendix VIII). Combination of $N_2Zn_2$ (150 kg N $ha^{-1}$ and 10 kg Zn $ha^{-1}$) produced the highest grain yield (8.91 t $ha^{-1}$). On the other hand, the lowest grain yield (1.77 t $ha^{-1}$) was found with the combination of $N_0Zn_0$ (0 kg N $ha^{-1}$ and 0 kg Zn $ha^{-1}$).

Application of $N_2Zn_2$ (150 kg N $ha^{-1}$ and 10 kg Zn $ha^{-1}$) produced 80.13% higher grain yield over control treatment.

## 4.9 Straw yield

### 4.9.1 Effect of nitrogen rate

From Table 7 and Appendix VIII, it was revealed that straw yield was significantly affected due to the different rate of nitrogen application. The maximum straw yield (7.40 t $ha^{-1}$) was achieved at highest rate of nitrogen ($N_2$) application (150 kg N $ha^{-1}$) whereas, the minimum (4.14 t $ha^{-1}$) was found with the control ($N_0$) treatment (0 kg N $ha^{-1}$). More straw yield could be explained as higher capability of hybrid rice to utilize more N through the expression of better growth by accumulating more dry matter. The results confirm the findings of Padmavathi (1997). The improvement in yield owing to the application of N-fertilizers might be brought by the beneficial effect of these on nutrient uptake, physiological growth. BRRI (2009) reported application of 150 kg N $ha^{-1}$ gave the highest yield. Hasanuzzaman *et al*. (2009) reported application of 200 kg N $ha^{-1}$ and USG @ 75 kg N $ha^{-1}$ gave highest straw yield. Awan *et al*. (2011) observed application of 156 kg N $ha^{-1}$ gave highest straw yield.

### 4.9.2 Effect of zinc rate

From Table 8 and Appendix VIII, it was revealed that straw yield was significantly affected due to the different rate of zinc application. The maximum straw yield (6.86 t $ha^{-1}$) was achieved at highest rate of zinc ($Zn_2$) application (10 kg Zn $ha^{-1}$) which was statistically identical with $Zn_3$ (6.68 t $ha^{-1}$) whereas, the minimum (4.56 t $ha^{-1}$) was found with the control ($Zn_0$) treatment (0 kg Zn $ha^{-1}$). Cheema *et al*. (2006) observed that straw yield showed positive correlation with the increase in $ZnSO_4.H_2O$ levels from 2.5 to 10 kg $ha^{-1}$. Cihatak *el al.* (2005) found that that Zinc fertilizer application significantly increased thestraw yields, uptake of Zn by plant. Ullah *el al.* (2001) found that soilapplication of zinc sulphate increased straw yields. 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)**.**

### 4.9.3 Interaction effect of nitrogen and zinc scheduling

From Table 9 and Appendix VIII, it was revealed that straw yield was significantly affected due to the interaction effect of different rate of nitrogen and zinc application in hybrid rice. The maximum straw yield (8.52 t $ha^{-1}$) was achieved at the combination treatment of $N_2Zn_2$ (150 kg N $ha^{-1}$ and 10 kg Zn $ha^{-1}$) which was statistically identical with $N_2Zn_3$ (8.29 t $ha^{-1}$) whereas, the minimum (3.17 t $ha^{-1}$) was found with the combination treatment of $N_0Zn_0$ (0 kg N $ha^{-1}$ and 0 kg Zn $ha^{-1}$).

## 4.10 Biological yield

### 4.10.1 Effect of nitrogen rate

Biological yield was significantly influenced by different rate of nitrogen in hybrid rice (Appendix VIII). The observation (Table 7) showed significantly maximum biological yield of 14.51 t $ha^{-1}$ obtained with 150 kg N $ha^{-1}$ ($N_2$) that was significantly higher over lower rate of nitrogen. However, the biological yield of 11.36 t $ha^{-1}$ due to 100 kg N $ha^{-1}$ ($N_1$), was significant higher over control (7.15 t $ha^{-1}$) treatment. The result agreed with the findings of Ahmed *et al.* (2005) who observed the effect of nitrogen dose on biological yield (t $ha^{-1}$) of rice.

### 4.10.2 Effect of zinc rate

The biological yield was affected by application of zinc (Table 8) and Appendix VIII). Significantly the maximum biological yield (13.18 t $ha^{-1}$) was found with $Zn_2$, which was higher than rest of the treatments which was statistically identical with $Zn_3$ (12.52 t $ha^{-1}$). However, the value of $Zn_2$ was found statistically at par with all treatment except control. Khan *et al*. (2007) reported that the increasing levels of Zn significantly influenced yield of rice.

### 4.10.3 Interaction effect of nitrogen and zinc scheduling

The interaction effect of different rate of nitrogen and zinc exerted significant influence on the biological yield of hybrid rice (Table 9 and Appendix VIII). Combination of $N_2Zn_2$ (150 kg N $ha^{-1}$ and 10 kg Zn $ha^{-1}$) produced the maximum biological yield (17.42 t $ha^{-1}$) which was statistically identical with $N_2Zn_3$ (16.52 t $ha^{-1}$). On the other hand, the minimum biological yield (4.93 t $ha^{-1}$) was found with the combination of $N_0Zn_0$ (0 kg N $ha^{-1}$ and 0 kg Zn $ha^{-1}$).

## 4.11 Harvest Index

### 4.11.1 Effect of nitrogen rate

From Table 7 and Appendix VII, it was revealed that significant variation in harvest index was observed due to various nitrogen management. The higher value of harvest index (48.33%) was found with 150 kg N $ha^{-1}$ ($N_2$) and the lowest value of harvest index (41.54%) was found with control ($N_0$). Awan *et al.* (2011) reported highest harvest index was found with 156 kg N $ha^{-1}$.

### 4.11.2 Effect of zinc rate

Date (Table 8 and Appendix VII) clearly indicate that there was significant variation in harvest index due to the various zinc management. The higher value of harvest index (47.20%) was reported with $Zn_2$ which was statistically similar to $Zn_1$ (46.11%) whereas, the lowest value of harvest index (38.60%) with control ($Zn_0$) treatment. Cheema *et al.* (2006) observed that harvest index showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg $ha^{-1}$. Babiker (1986) observed that harvest index was significantly affected by rice cultivars and $ZnS0_4$ rates.

### 4.11.3 Interaction effect of nitrogen and zinc scheduling

From Table 9 and Appendix VIII, it revealed that harvest index was significantly affected due to the interaction effect of different rate of nitrogen and zinc application in hybrid rice. The higher value of harvest index (51.12%) was achieved at the combination treatment of $N_2Zn_2$ (150 kg N ha$^{-1}$ and 10 kg Zn ha$^{-1}$) which was statistically similar to $N_2Zn_1$ (50.03%). On the other hand, the lowest value of harvest index (35.80%) was found with the combination treatment of $N_0Zn_0$ (0 kg N ha$^{-1}$ and 0 kg Zn ha$^{-1}$).

**Table 7. Effect of nitrogen scheduling on the yield and harvest index of BRRI hybrid dhan2**

| Treatment | Grain yield (t ha$^{-1}$) | Straw yield (t ha$^{-1}$) | Biological yield (t ha$^{-1}$) | Harvest index (%) |
|---|---|---|---|---|
| $N_0$ | 3.01 c | 4.14 c | 7.15 c | 41.54 c |
| $N_1$ | 5.01 b | 6.35 b | 11.36 b | 43.48 b |
| $N_2$ | 7.11 a | 7.40 a | 14.51 a | 48.33 a |
| **LSD $_{(0.05)}$** | **0.45** | **0.59** | **1.72** | **1.28** |
| **CV (%)** | **6.92** | **11.42** | **10.71** | **9.27** |

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

**Note:** $N_0$ – 0 kg ha$^{-1}$ (control), $N_1$ – $N_1$ – 100 kg ha$^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and $N_2$ – 150 kg ha$^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]

**Table 8. Effect of zinc scheduling on the yield and harvest index of BRRI hybrid dhan2**

| Treatment | Grain yield (t ha$^{-1}$) | Straw yield (t ha$^{-1}$) | Biological yield (t ha$^{-1}$) | Harvest index (%) |
|---|---|---|---|---|
| $Zn_0$ | 2.95 d | 4.56 c | 7.52 c | 38.60 c |
| $Zn_1$ | 5.06 c | 5.74 b | 10.81 b | 46.11 ab |
| $Zn_2$ | 6.32 a | 6.86 a | 13.18 a | 47.20 a |
| $Zn_3$ | 5.84 b | 6.68 a | 12.52 a | 45.89 b |
| **LSD $_{(0.05)}$** | **0.45** | **0.59** | **1.72** | **1.28** |
| **CV (%)** | **6.92** | **11.42** | **10.71** | **9.27** |

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

**Note:** $Zn_0$ **-** 0 kg ha$^{-1}$ (control), $Zn_1$–5 kg ha$^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], $Zn_2$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and $Zn_3$ – 10 kg $ha^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]

**Table 9. Interaction effect of nitrogen and zinc scheduling on the yield and harvest index in BRRI hybrid dhan2**

| Treatment combination | Grain yield ($t\ ha^{-1}$) | Straw yield ($t\ ha^{-1}$) | Biological yield ($t\ ha^{-1}$) | Harvest index (%) |
|---|---|---|---|---|
| **$N_0Zn_0$** | 1.77 j | 3.17 g | 4.93 f | 35.80 g |
| **$N_0Zn_1$** | 3.03 i | 3.98 f | 7.01 e | 43.17 e |
| **$N_0Zn_2$** | 3.78 gh | 4.76 e | 8.54 de | 44.25 d |
| **$N_0Zn_3$** | 3.49 h | 4.63 e | 8.12 de | 42.95 e |
| **$N_1Zn_0$** | 2.93 i | 4.86 e | 7.79 e | 37.65 f |
| **$N_1Zn_1$** | 5.03 f | 6.11 c | 11.15 cd | 45.14 cd |
| **$N_1Zn_2$** | 6.28 d | 7.31 b | 13.58 b | 46.22 c |
| **$N_1Zn_3$** | 5.80 e | 7.11 b | 12.92 bc | 44.91 d |
| **$N_2Zn_0$** | 4.16 g | 5.66 d | 9.83 d | 42.36 e |
| **$N_2Zn_1$** | 7.14 c | 7.13 b | 14.26 b | 50.03 ab |
| **$N_2Zn_2$** | 8.91 a | 8.52 a | 17.42 a | 51.12 a |
| **$N_2Zn_3$** | 8.23 b | 8.29 a | 16.52 a | 49.81 b |
| **$LSD_{(0.05)}$** | **0.45** | **0.59** | **1.72** | **1.28** |
| **CV (%)** | **6.92** | **11.42** | **10.71** | **9.27** |

In a column means having similar letter (s) are statistically similar and those having dissimilar letter(s) differ significantly by LSD at 0.05 levels of probability

**Note:** $N_0$ – 0 kg $ha^{-1}$ (control), $N_1$ – $N_1$ – 100 kg $ha^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and $N_2$ – 150 kg $ha^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]
$Zn_0$ - 0 kg $ha^{-1}$ (control), $Zn_1$–5 kg $ha^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], $Zn_2$ – 10 kg $ha^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and $Zn_3$ – 10 kg $ha^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]

# CHAPTER V

# SUMMARY AND CONCLUSION

The field experiment was conducted at the experimental plot of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 during the period from November, 2019 to May, 2020 in *boro* season to find out the effect of nitrogen and zinc scheduling on performance of hybrid rice. BRRI hybrid dhan2 was used as planting material in this study. The experiment consisted of two factors: Factor A: Nitrogen management (3 levels) as i) $N_0$ – 0 kg ha$^{-1}$ (control), ii) $N_1$ – 100 kg ha$^{-1}$ [50% RDN at 15 DAT + 50% RDN at 35 DAT] and iii) $N_2$ – 150 kg ha$^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT]. Factor B: Zinc management (4 levels) as i) $Zn_0$ - 0 kg ha$^{-1}$ (control), ii) $Zn_1$ – 5 kg ha$^{-1}$ [0.50% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting)], iii) $Zn_2$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] and iv) $Zn_3$ – 10 kg ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 100 DAT (milking)]. The experiment was laid out in a Randomized Complete Block Design (Factorial) with three (3) replications. Total 36 unit-plots was made for the experiment with 12 treatments. Each plot was of required size. Data on different growth and yield parameter of rice were recorded and significant variation was recorded for different treatments.

In case of different nitrogen level, at 25, 55, 85 DAT and at harvest stage, the maximum number of tillers hill$^{-1}$ (15.48, 24.15, 18.55 and 17.16 tillers hill$^{-1}$, respectively) was observed with 150 kg N ha$^{-1}$ ($N_2$) and the minimum number of tillers hill$^{-1}$ (9.53, 16.51, 13.32 and 10.14 tillers hill$^{-1}$, respectively) with 0 kg N ha$^{-1}$ ($N_0$) treatment. The highest LAI (0.94, 4.90 and 5.49, respectively) was found at 25, 55 and 85 DAT due to the effect of 150 kg N ha$^{-1}$ ($N_2$) whereas, the lowest LAI (0.48, 1.78 and 2.87, respectively) was found at 25, 55 and 85 DAT due to the effect of 0 kg N ha$^{-1}$ ($N_0$). At 25, 55 and 85 DAT, the maximum CGR (0.56, 4.21 and 5.19 g running m$^{-1}$ day$^{-1}$, respectively) was recorded with 150 kg N ha$^{-1}$ ($N_2$). On the other hand, the minimum CGR (0.26, 1.08 and 2.55 g running

$m^{-1}$ $day^{-1}$, respectively) was found at 25, 55 and 85 DAT due to the effect of 0 kg N $ha^{-1}$ ($N_0$). The highest panicle number $hill^{-1}$ (14.25), the longest panicle (25.73 cm), the highest grain number $panicle^{-1}$ (111.95), the maximum 1000-grain weight (25.50 g), significantly the highest grain yield (7.11 t $ha^{-1}$), the maximum straw yield (7.40 t $ha^{-1}$), significantly the maximum biological yield of 14.51 t $ha^{-1}$ and the highest value of harvest index (48.33%) were found from $N_2$ (150 kg N $ha^{-1}$) treatment. Whereas, the lowest panicle number $hill^{-1}$ (7.50), the shortest panicle (22.53 cm), the lowest grain number $panicle^{-1}$ (84.95), the minimum 1000-grain weight (21.33 g), the lowest grain yield of 2.97 t $ha^{-1}$, the minimum straw yield (4.14 t $ha^{-1}$), the lowest biological yield of 7.15 t $ha^{-1}$ and the lowest value of harvest index (41.54%) was obtained from no nitrogen application (0 kg N $ha^{-1}$).

In case of different zinc application rate, at 25, 55, 85 DAT and at harvest, the maximum number of tillers $hill^{-1}$ (13.78, 22.57, 18.68 and 16.42 and tillers $hill^{-1}$, respectively) were found from 10 kg Zn $ha^{-1}$ ($Zn_2$) while the minimum number of tillers $hill^{-1}$ (10.83, 16.64, 13.94 and 12.22 tillers $hill^{-1}$, respectively) was recorded from 0 kg Zn $ha^{-1}$($Zn_0$). The highest LAI (0.75, 3.68 and 4.42 at 25, 55 and 85 DAT, respectively) was obtained from the treatment $Zn_2$ (10 kg Zn $ha^{-1}$) whereas, the lowest LAI (0.52, 2.95 and 3.75, respectively) at 25, 55 and 85 DAT was found from the treatment $Zn_0$ (0 kg Zn $ha^{-1}$). At 25, 55 and 85 DAT, numerically the maximum CGR (0.43, 3.41 and 4.68 g running $m^{-1}$ $day^{-1}$) was recorded with $Zn_2$ (10 kg Zn $ha^{-1}$) and the minimum CGR (0.36, 1.75 and 3.12 g running $m^{-1}$ $day^{-1}$ at 25, 55 and 85 DAT, respectively) was recorded with $Zn_0$ (0 kg Zn $ha^{-1}$). Numerically the longest panicle (25.30 cm) was recorded in 10 kg Zn $ha^{-1}$ ($Zn_3$) and the shortest panicle (24.35) obtained from 5 kg Zn $ha^{-1}$ ($Zn_1$) treatment. The highest panicle number $hill^{-1}$ (13.33), the highest value of grains $panicle^{-1}$ (106.11), the maximum weight of 1000-grains (24.38 g), the highest grain yield (6.32 t $ha^{-1}$), the maximum straw yield (6.86 t $ha^{-1}$), the maximum biological yield (13.18 t $ha^{-1}$) and the highest value of harvest index (47.20%) was found from $Zn_2$ (10 kg Zn $ha^{-1}$) treatment. On the other hand, the lowest panicle number hill$^{-1}$ (9.78), the lowest value of grains panicle$^{-1}$ (89.01), the lowest weight of 1000-grains (22.60 g), the lowest grain yield (2.95 t ha$^{-1}$), the minimum straw yield (4.56 t ha$^{-1}$), the minimum biological yield (7.52 t ha$^{-1}$) and the lowest value of harvest index (38.60%) was recorded from $Zn_0$ (0 kg Zn ha$^{-1}$) treatment.

The interaction effect of nitrogen and zinc scheduling showed significant impact on most of the parameters under study. At 25, 55, 85 DAT and at harvest, the maximum number of tillers hill$^{-1}$ (17.13, 27.85, 21.55 and 19.78, respectively) was achieved by $N_2Zn_2$ (150 kg N ha$^{-1}$ and 10 kg Zn ha$^{-1}$) treatment combination. At 25, 55. 85 DAT and at harvest, the minimum number of tillers hill$^{-1}$ (8.29, 13.65, 11.55 and 8.56, respectively) was found with $N_0Zn_0$ (0 kg N ha$^{-1}$ and 0 kg Zn ha$^{-1}$). At 25, 55 and 85 DAT, the highest LAI (1.07, 5.32 and 5.83, respectively) was observed with $N_2Zn_2$ (150 kg N ha$^{-1}$ and 10 kg Zn ha$^{-1}$) and at 25, 55 and 85 DAT, the lowest LAI (0.38, 1.55 and 2.58, respectively) was found by $N_0Zn_0$ (0 kg N ha$^{-1}$ and 0 kg Zn ha$^{-1}$). At 25 DAT, the maximum CGR (0.62 g running m$^{-1}$ day$^{-1}$) was observed with $N_2Zn_3$ (150 kg N ha$^{-1}$ and 10 kg Zn ha$^{-1}$) and at 55 and 85 DAT, the maximum CGR (5.23 and 5.96 g running m$^{-1}$ day$^{-1}$, respectively) was found by $N_2Zn_2$ (150 kg N ha$^{-1}$ and 10 kg Zn ha$^{-1}$). At 25, 55 and 85 DAT, the minimum CGR (0.23, 0.69 and 1.95 g running m$^{-1}$ day$^{-1}$) was observed with $N_0Zn_0$ (0 kg N ha$^{-1}$ and 0 kg Zn ha$^{-1}$). The longest panicle (26.17 cm) was recorded in 150 kg N ha$^{-1}$ and 10 kg Zn ha$^{-1}$ ($N_2Zn_3$) combination and the shortest panicle length (23.03 cm) was obtained from no nitrogen and zinc application ($N_0Zn_1$). The highest panicle number hill$^{-1}$ (17.17), the highest number grains panicle$^{-1}$ (119.74), the maximum 1000-seed weight (26.43 g), the highest grain yield (8.91 t ha$^{-1}$), the maximum straw yield (8.52 t ha$^{-1}$), the maximum biological yield (17.42 t ha$^{-1}$) and the higher value of harvest index (51.12%) was found from the combination treatment of $N_2Zn_2$ (150 kg N ha$^{-1}$ and 10 kg Zn ha$^{-1}$). On the other hand, the lowest panicle number hill$^{-1}$ (6.63), the lowest grain number panicle$^{-1}$ (76.22), the minimum weight of 1000-seed (20.49 g), the lowest grain yield (1.77 t ha$^{-1}$), the minimum straw yield (3.17 t ha$^{-1}$), the minimum biological yield (4.93 t ha$^{-1}$) and the lowest value of harvest index (35.80%) was found with the combination treatment of $N_0Zn_0$ (0 kg N ha$^{-1}$ and 0 kg Zn ha$^{-1}$).

## Conclusion

The application of 150 kg N ha$^{-1}$ [50% RDN at 15 DAT + 25% RDN at 35 DAT + 25% RDN at 50 DAT] and 10 kg Z ha$^{-1}$ [0.25% $ZnSO_4$. $H_2O$ spray at 75 DAT (booting) + 0.25% Zn spray at 90 DAT (anthesis)] provided significantly higher grain yield compared to other treatments under study.

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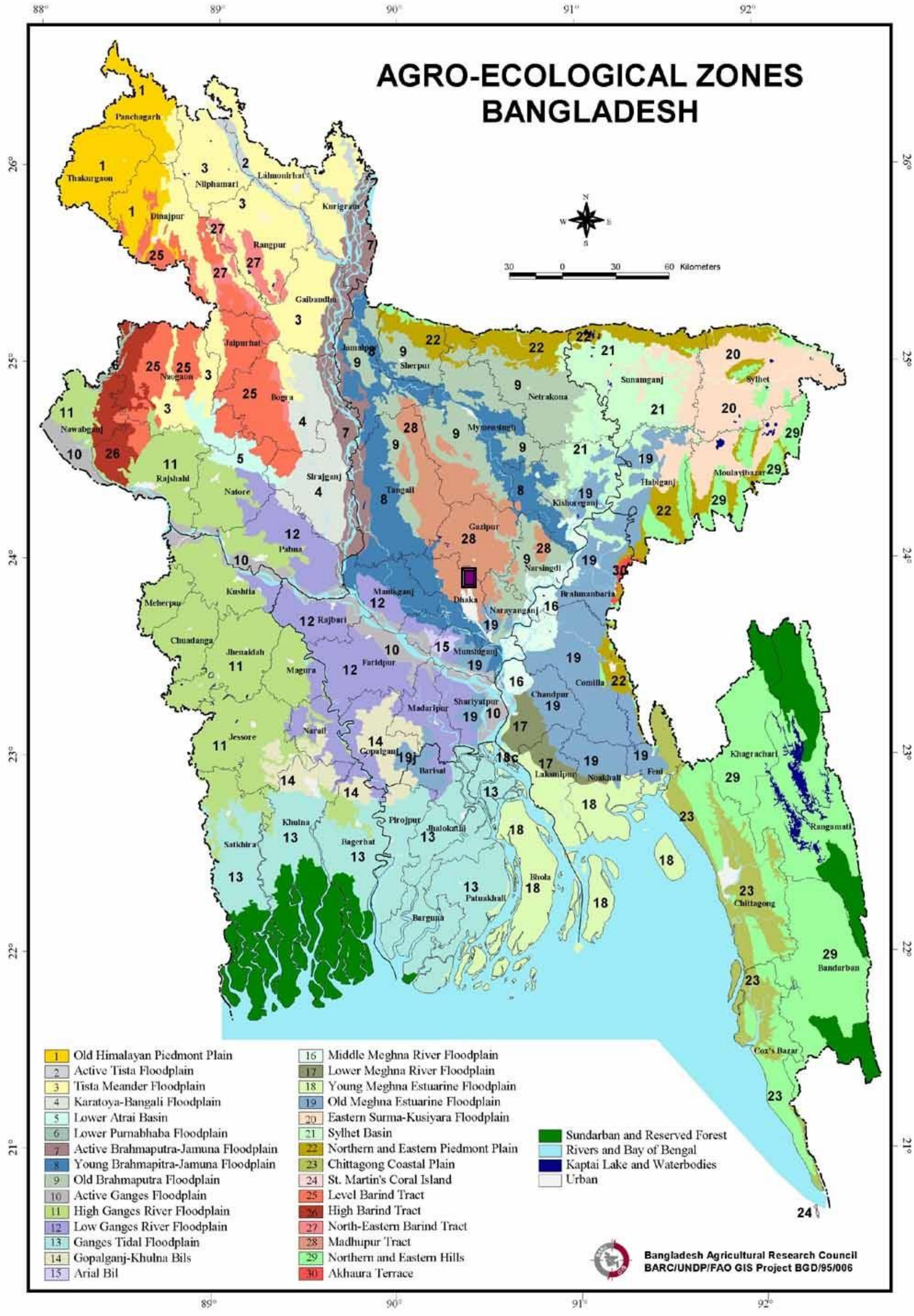
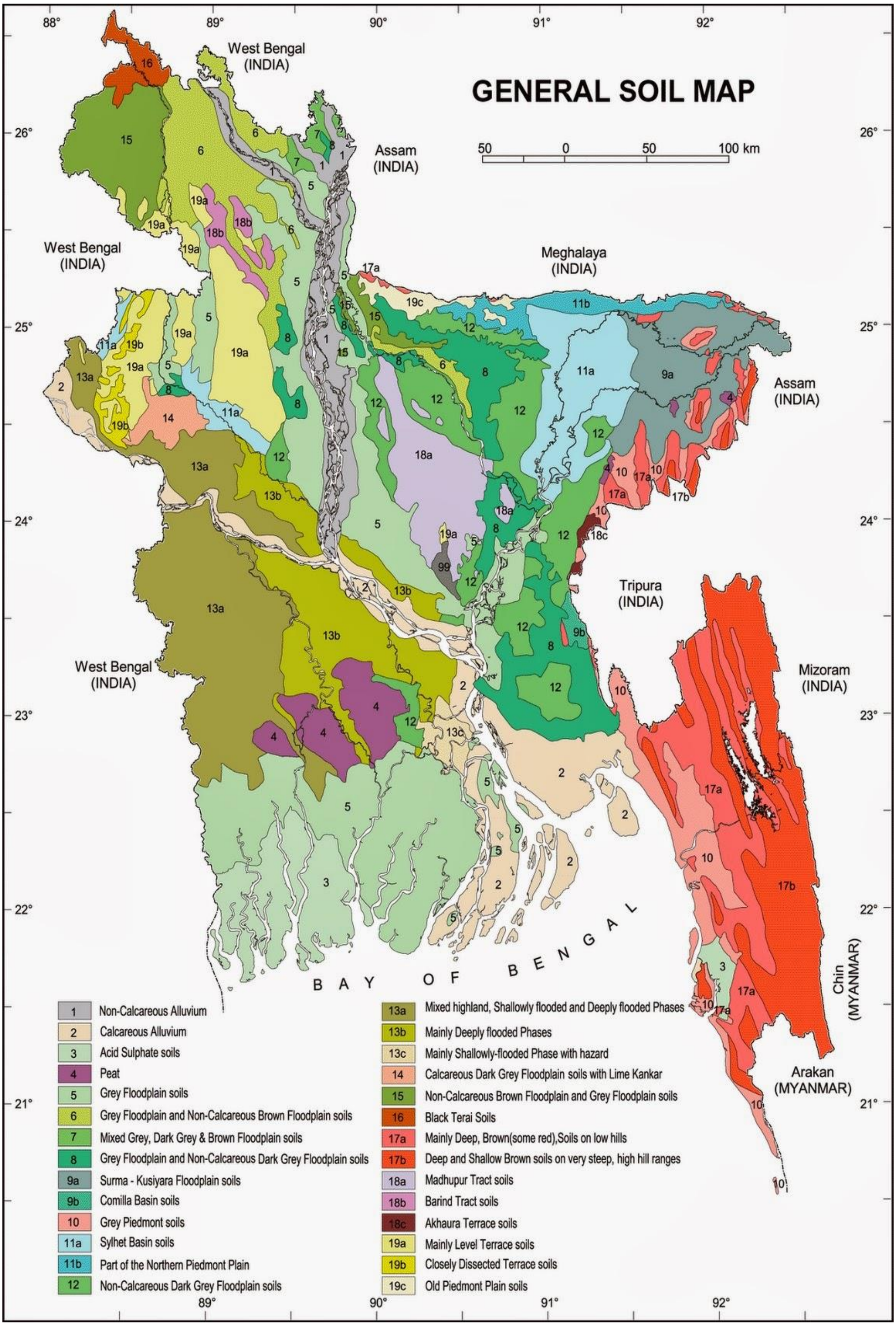
# APPENDICES

## Appendix I (A): Map showing the experimental sites under study




**The experimental site under study**

## Appendix I(B): Map showing the general soil sites under study



**Appendix II:** Characteristics of soil of experimental site is analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

| Morphological features | Characteristics |
|---|---|
| Location | Experimental field, SAU, Dhaka |
| AEZ | Madhupur 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 | Boro–Aman–Boro |

B. Physical and chemical properties of the initial soil

| Characteristics | Value |
|---|---|
| % Sand | 27 |
| % Silt | 43 |
| % clay | 30 |
| Textural class | Silty-clay |
| pH | 5.5 |
| Organic carbon (%) | 0.43 |
| Organic matter (%) | 0.75 |
| Total N (%) | 0.075 |
| Available P (ppm) | 21.00 |
| Exchangeable K (meq/ 100 g soil) | 0.11 |
| Available S (ppm) | 43 |

Source: SRDI, 2018

**Appendix III:** Monthly average of Temperature, Relative humidity, total Rainfall and sunshine hour of the experiment site during the period from November 2019toMay 2020

| Year | Month | Temperature | | | Relative Humidity (%) | Rainfall (mm) | Sunshine (Hour) |
|---|---|---|---|---|---|---|---|
| | | Max (°C) | Min (°C) | Mean (°C) | | | |
| 2019 | November | 32 | 24 | 29 | 65 | 42.8 | 349 |
| | December | 27 | 19 | 24 | 53 | 1.4 | 372 |
| 2020 | January | 27 | 18 | 23 | 50 | 3.9 | 364 |
| | February | 30 | 19 | 26 | 38 | 3.1 | 340 |
| | March | 35 | 24 | 31 | 38 | 19.6 | 353 |
| | April | 38 | 25 | 33 | 54 | 292.4 | 315 |
| | May | 37 | 27 | 33 | 59 | 152.5 | 297 |

**Appendix IV. Analysis of variance (mean square) of tiller number hill$^{-1}$ at different DAT**

| Source of variation | Degrees of freedom | Tiller number hill$^{-1}$ | | | |
|---|---|---|---|---|---|
| | | 25 DAT | 55 DAT | 85 DAT | Harvest |
| Replication | 2 | 5.852 | 80.983 | 156.225 | 6.516 |
| Nitrogen (A) | 2 | 10.897* | 49.245* | 170.324* | 53.933* |
| Zinc (B) | 3 | 6.051* | 49.026* | 110.420* | 3.034* |
| A×B | 6 | 0.549** | 3.452** | 9.923** | 6.954** |
| Error | 22 | 1.305 | 8.520 | 29.517 | 0.585 |

*** and ** indicate significant at 5% and 1% level of probability, respectively.**

**Appendix V. Analysis of variance (mean square) of Leaf area index at different DAT**

| Source of variation | Degrees of freedom | Leaf area index | | |
|---|---|---|---|---|
| | | 25 DAT | 55 DAT | 85 DAT |
| **Replication** | **2** | **0.239** | **7.238** | **1.646** |
| **Nitrogen** | **2** | **13.411*** | **571.676*** | **207.136*** |
| **(A)** | **3** | **16.141**** | **546.668**** | **167.304**** |
| **Zinc (B)** | **6** | **0.396*** | **8.145**** | **0.001**** |
| **A×B** | **22** | **0.283** | **0.825** | **6.063** |
| **Error** | | | | |

*** and ** indicate significant at 5% and 1% level of probability, respectively**

**Appendix VI. Analysis of variance (mean square) of Crop growth rate at different DAT**

| Source of variation | Degrees of freedom | Crop growth rate | | |
|---|---|---|---|---|
| | | 25 DAT | 55 DAT | 85 DAT |
| **Replication** | **2** | 1.970 | 41.200 | 149.040 |
| **Nitrogen (A)** | **2** | 50.408* | 119.856* | 205.300NS |
| **Zinc (B)** | **3** | 9.672NS | 26.023* | 79.191* |
| **A×B** | **6** | 0.577* | 6.475* | 3.825* |
| **Error** | **22** | 2.327 | 13.856 | 25.211 |

*** and ** indicate significant at 5% and 1% level of probability, respectively**

**NS = non-significant**

**Appendix VII. Analysis of variance (mean square) of yield components**

| Source of variation | Degrees of freedom | No. of panicles $hill^{-1}$ | Panicle length | No. of grain $panicle^{-1}$ | 1000-grain weight |
|---|---|---|---|---|---|
| **Replication** | **2** | 156.208 | 80.330 | 31.342 | 28.073 |
| **Nitrogen (A)** | **2** | 62.519* | 65.135* | 8.090** | 46.212* |
| **Zinc (B)** | **3** | 3.558** | 11.910NS | 2.122** | 25.339* |
| **A×B** | **6** | 3.345** | 2.393** | 1.673** | 2.480* |
| **Error** | **22** | 20.387 | 48.889 | 20.423 | 10.007 |

*** and ** indicate significant at 5% and 1% level of probability, respectively**
**NS = non-significant**

**Appendix VIII. Analysis of variance (mean square) of yield and harvest index**

| Source of variation | Degrees of freedom | Grain yield | Straw yield | Biological yield | Harvest index |
|---|---|---|---|---|---|
| **Replication** | 2 | 2.765 | 7.313 | 6.516 | 10.002 |
| **Nitrogen (A)** | 2 | 0.633* | 145.606* | 53.933* | 20.601** |
| **Zinc (B)** | 3 | 1.753* | 12.964** | 3.034* | 23.761** |
| **A×B** | 6 | 0.355* | 3.995** | 6.954** | 11.002** |
| **Error** | 22 | 0.365 | 0.310 | 0.585 | 0.002 |

*** and ** indicate significant at 5% and 1% level of probability, respectively**