EFFECT OF ZINC AND SULPHUR ON GROWTH AND YIELD OF BRRI HYBRID DHAN2 (*Oryza sativa L.*)

A THESIS

BY

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CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) is widely grown in tropical and subtropical regions (Singh *et al.*, 2012). It is the staple food of more than three billion people in the world (Jahan *et al.*, 2017). Globally, rice is grown on 153 Mha (FAO, 2019), though its production and consumption is concentrated in Asia, where more than 90% of all rice is consumed. Rice alone constitutes 97% of the food grain production in Bangladesh (BBS, 2012). It dominates over all other crops and covers 75% of the total cropped area (DAE, 2020). Among three rice seasons, *Boro* rice covers about 48.97% of total rice area and contributes to 38.14% of total rice production in the country (BBS, 2012). Bangladesh ranks 4th in both area and production and 6th in per hectare production of rice (Sarkar *et al*., 2016). About two millions of people are adding every year which will be 30 million over the next 20 years and thus, to meet up the food demand for this over population, Bangladesh needs 37.26 million tons of rice for the year 2020 (BRRI, 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 Bangladesh, rice covers an area of about 11,420,725 ha and total production is about 34,710,417 metric tons (BBS, 2019). 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}). The low productivity of rice in Bangladesh is attributed by several factors including balance nutrition. Balanced nutrition especially application of sulphur and zinc to the rice crop is one of the important inputs that can enhance productivity to a great extent. In our country, there is tendency to use indiscriminate amount of nitrogenous fertilizers and very limited amount of other nutrients' containing high analysis chemical fertilizers (BRRI, 2018). Rice and rice based cropping system have important role in the Bangladesh to increase food production for a rapidly growing population.

Our farmers apply N, P and K fertilizers widely, it is found that application of micronutrient such as sulphur and zinc is not a usual practices. A marked higher incidence of micronutrient deficiency is found in crop due to intensive cropping, loss of fertile top soil and losses of nutrient through leaching (Rahman *et al.*, 2008; Singh *et al.*, 2011).

Nutrient stresses in Bangladesh soils are increasing day by day. Due to intensification of cropland rapid adoption of improved cultivars has not only increased yield but also have significantly increased the output of nutrients and, where there has been an imbalance between outputs and inputs, has resulted in declining soil fertility and an increase in the incidence of deficiencies of certain plant nutrients, including sulphur and zinc. On an average to produce one ton of grain of high-yielding varieties of rice, remove about 22 kg N, 7 kg P_2O_5, 32 kg K_2O, 5 kg MgO, 4 kg CaO, 1 kg S and 40g Zn from the soil (Chaudhary *et al*., 2007).

Sulphur (S) is involved in amino acid and protein synthesis, enzymatic and metabolic activities in plants, which account for approximately 90% of organic S in the plant. Its deficiency is fast emerging in areas under oilseeds and pulses due to higher removal of S by crops (Singh and Kumar, 2009). The sulphur requirement of rice varies according to the nitrogen supply. When S becomes limiting, addition of N does not change the yield or protein level of plants. Sulphur is required early in the growth of rice plants. If it is limiting during early growth, then tillers number and therefore final yield will be reduced (Blair and Lefroy, 1987). Zinc is one of the most important micronutrient essential for plant growth especially for rice grown under submerged condition. Zinc deficiency continues to be one of the key factors in determining rice production in several parts of the country (Muthukumararaja and Sriramachandrasekharan, 2012). Zn deficiency is the most widespread micronutrient disorder in lowland rice and application of Zn along with NPK fertilizer increases the grain yield dramatically in most cases (Fageria *et al.,* 2011; Singh et al., 2011). Apart from major nutrients Zn is very much responsive to high intensive cereal based cropping system. Zinc is required in a large number of enzymes and plays an essential role in DNA transcription. To give impetus to the vegetative growth zinc plays a vital role especially under low temperature ambient and rhizosphere regime. Adequate availability of zinc to young and developing plants is certain promise for sufficient growth and development. To understand zinc their dynamic in soil plant system need to be ascertained. Its availability in soil is mainly governed by pH and p concentration. Zn translocation in the plant is also administrating by P: Zn ration in the plant tissue, especially during seed development phase (Muthukumararaja and

Sriramachandrasekharan, 2012). Zinc role is as multifaceted as the interface that means its availability. Physiologically its role in a plant is either as a metal constituent in an enzymes or as a functional co-factor of number of enzymes reactions.In general zinc deficient plant show signs of low levels of auxins such as indole acetic acid (IAA). Zinc plays a greater role during reproductive phase especially during fertilization. Remarkably pollen grain contains zinc in very high quantity. At the time of fertilization most of zinc is diverted to seed only (Fageria *et al.,* 2011). Reduction in yield of rice is often blamed to zinc-sulphur deficiency. Zn deficiency is the most widespread micronutrient disorder in lowland rice and application of Zn along with NPK fertilizer increases the grain yield dramatically in most cases (Rahman *et al.,* 2008; Chaudhary *et al.,* 2007). The above discussion revealed that scant information is available on the effects of S and Zn application hybrid in rice production in Bangladesh. So, there is a need to ascertain and promote the uses of types of fertilizers required to correct the deficiency of all these nutrients especially sulphur and zinc. Keeping in the view of the importance of rice in Bangladesh and role of sulphur and zinc nutrient in their crop physiology and ultimately in the economic yield, this experiment was undertaken with BRRI Hybrid dhan2 in *Boro* season to achieve the following objectives.

- To study the effects of sulphur and zinc nutrients on growth and yield of BRRI hybrid dhan2 in *Boro* season.
- To determine the optimum doses of sulphur and zinc fertilizers for improved growth and yield components of afore-mentioned rice variety.

CHAPTER II

REVIEW OF LITERATURE

Rice crop is interwoven in the cultural, social and economic lives of millions of Bangladeshis and it holds the key for food and nutritional security of the country. It is consumed as the staple food and has been given the highest priority in meeting the demands of its ever-increasing population in Bangladesh. The use of high dose of NPK, S and Zn content fertilizers is the recent trend for maximum rice grain yield. Few years ago, S was not an element of farmer’s concern but at present it holds their importance for maximum crop yield particular for rice. Similarly, zinc was not considered as an element to be applied to the rice crop due to natural reserve of zinc in soil in adequate amount. But now a day, researchers likely to recommend a proper dose of zinc to be supplied to the rice crop for getting maximum yield.

However, some of the important and informative works and research findings related to the morpho-physiological attributes, yield contributing characters and yield regarding effect of S and Zn application, so far been done at home and abroad, reviewed in this chapter under the following headings.

2.1. Effect of sulphur on rice

2.1. 1. Role of sulphur

Sulphur is one of the essential macronutrients of plant. It was observed by different findings of many researchers that sulphur has positive influence on yield and nutrient content of rice. If sulphur is limiting, it may limit the response to other plant nutrients and thus yield is reduced. Sulphur is essential to the growth and development of plant since it is a constituent of S containing amino acids and enzymes (Tiwari *et al.*, 1997). Sulphur is required for the synthesis of proteins, vitamins, chlorophyll (Tisdale *et al.*, 1999) and it is also required for the synthesis of S containing aminoacids such as cysteine and methionine which are essential components of protein (Tisdale *et al.*, 1999). Sulphur containing amino acids are important in the synthesis of other compounds within the cells, such as sulphur adenosyl methionine serves as a methyl donor in biosynthesis of many component including chlorophyll, flavonoids and sterols. Sulphur containing ferredoxin helps in electron transfer, which is involved in photosynthesis and in reduction of oxidized components such as nitrite.

Sulphur is needed for the synthesis of coenzyme A, which is involved in the oxidation, and synthesis of fatty acids and the synthesis of amino acids (Tisdale *et al.,* 1999). Sulphur stimulates root growth and seed formation (Thomson *et al*, 1970).

Plant membrane structure and also function of it require S, sulpho-lipids being essential membrane compounds and intimately involved in organization of chlorophyll in chloroplast lamellae (Smith and Siregar, 1983).

2.1.2. Sulphur deficiency symptoms

Chlorosis extends to the older leaves, redding and purpling develop in the stem and leaves (Yoshida and Chaudhury, 1997). The maturity of seed is delayed in the absence of adequate sulphur (Brady, 1996).

2.1.3. Causes of sulphur deficiency

In Bangladesh, submerged soil is one of the reasons of sulphur deficiency in case of rice. There is often general yellowing of the whole plants but the symptoms appear first or mostly marked on the younger leaves (Rao *et al* 1980). Sulphur deficiency included reduced growth and chlorosis or yellowing of the leaves due to diminished chlorophyll in leaves (Tabatabai, 1986).

2.2. Effect of sulphur on growth and yield characters of rice

Jena and Kabi (2012) observed the effect of gromorbentonite S pastilles and gypsum on yield and nutrient uptake by hybrid rice-potato-green gram cropping system. Application of S significantly increased the grain and straw yield, nutrient uptake by hybrid rice-potato-green gram cropping system. A dose of 60 kg S ha^{-1} through S-bentonite pastilles increased the yield of hybrid rice, potato and green gram over control by 34, 21 and 18 percent, respectively.

Rasavel and Ravichandran (2012) conducted field experiments to study the interaction of phosphorus, sulfur and zinc on growth and yield of rice in neutral and alkali soils. The results revealed significant interactions among P, S and Zn on growth and yield of rice. The highest plant height (52.8 cm), number of tillers $hill^{-1}$(16.3), LAI (5.12), panicle length (21.6 cm) and number of grain $panicle^{-1}$ (108.3) was noticed with application of 20 kg S ha^{-1} + 10 kg Zn ha^{-1} (T_8) in alkali soils respectively. The highest grain (4678 kgha^{-1}) and straw yields (5642 kg ha^{-1}) was noticed with application of 20 kg S + 10 kg Zn ha^{-1} in alkali soils.

Devi *et al*. (2012) studied the effect of sulphur and boron fertilization on yield, quality and nutrient uptake by soybean under upland condition. The study revealed that yield attributing characters like number of branches per plant, pods per plant and 100 seed weight and yield were increased with the application of sulphur and boron as compare to control. The overall result revealed that application of 30 kg sulphur per hectare and 1.5 kg boron per hectare were found to be the optimum levels of sulphur and boron for obtaining maximum yield attributes, yield, oil and protein content, total uptake of sulphur and boron, net return, cost and benefit ratio of soybean under upland condition as compare to other levels of sulphur and boron respectively.

Singh *et al.* (2012) conducted a field experiment to evolve suitable nutrient management system with respect to one secondary nutrient (sulphur) and one micronutrient (zinc) in rice for Indo- Gangetic plains of Bihar at ICAR Research Complex for Eastern Region Patna during 2008-09. Total 16 treatment combination was tested i.e. four level of sulphur S_1 (0 kg), S_2 (20 kg), S_3 (30 kg), and S_4 (40 kg) and zinc Zn_1 (0 kg), Zn_2 (4 kg), Zn_3 (5 kg) and Zn_4 (6 kg) were applied in combination, respectively, was applied on hectare basis. Application of sulphur at 20 kg ha^{-1}produced significantly taller plants over no application of sulphur (S_1) at all the growth stages. Plots received 20 kg sulphur produces significantly higher LAI over no application and produced at par with other tested levels of sulphur in most of the phenological stages. Yield attributes were also influenced significantly with graded doses of sulphur. In case of sulphur, application at 20 kg ha^{-1} produced rice grain 7.25 t ha^{-1} significantly over control (S_1) however it produced significantly lower than other tested levels of i.e. S_3 (7.44 t ha^{-1}) and S_4 (7.51 t ha^{-1}). Harvest index (HI) was not influenced significantly by any of tested factors.

Bhuiya n*et al*. (2011) investigated the integrated use of organic and inorganic fertilizers on the yield of T. *Aus* and mungbean in a Wheat-T. *Aus*/mungbean-T.*Aman* cropping sequence at the Bangladesh Agricultural University Farm, Mymensingh. The rates of N, P, K and S for T. *Aus* rice were 60, 12, 32 and 5 kg ha^{-1}for MYG, and 90, 18, 48 and 7.5 kg ha^{-1}for HYG, respectively. The variety BR 26 for T. *Aus* rice was planted in all three years. The results showed that grain yields (3.46 t ha^{-1}) and straw yields (5.19 t ha^{-1}) of T. *Aus* rice (mean of three years) was increased significantly by the application of fertilizers. The application of chemical fertilizers, NPKS (HYG) remarkably increased the crop yields while the lowest mean grain yields of 1.48 t $ha^{-1}$for T. *Aus* and 0.42 t ha^{-1} for mungbean were recorded in the unfertilized control plots.

Ji-ming *et al.* (2011) conducted a field experiment to study the effects of manure application on rice yield and soil nutrients in paddy soil. The results show that the long-term applications of green manure combined with chemical fertilizers (N, P, K, S) are in favor of stable and high yields of rice.

Jawahar and Vaiyapuri (2010) carried out a field experiment at Experimental Farm, Annamalai University, Annamalai Nagar, Tamil Nadu, India during 2007-2008 to study the effect of sulphur and silicon fertilization on yield, nutrient uptake and economics of rice. Among the different levels of sulphur, application of 45 kg S ha^{-1}recorded maximum grain and straw yield of rice, which was closely followed by 30 kg S ha^{-1}. This treatment recorded 18.12, 7.47 and 2.43 per cent increase over 0, 15 and 30 kg S ha^{-1}. Higher grain and straw yield due to S may be attributed to increase in growth and yield characters of rice and to be stimulating effect of applied S in the synthesis of chloroplast protein resulting in greater photosynthetic efficiency, which in turn increased the yield.

Patel *et al.* (2010) conducted a field experiment to study the performance of rice and a subsequent wheat crop along with changes in properties of a sodic soil treated with gypsum, pressmud (sugar factory waste), and pyrite under draining and non-draining conditions in a greenhouse experiment. The highest rice yield was obtained with pressmud applied at a rate of 50 and 75 % gypsum requirement.

Rahman *et al*. (2009) studied the effect of different levels of sulphur on growth and yield of BRRI dhan41 at Soil Science Field Laboratory of Bangladesh Agricultural University (BAU), Mymensingh during T. *Aman* season of 2007. The treatments used in the experiment were T_0 (without S), T_1 (50% RFD of S), T_2 (75% RED of S), T_3 (100% RFD of S), T_4 (125% RFD of S), T_5 (150% RFD of S), T_6 (175% RFD of S) and T_7 (200% RFD of S). All yield contributing characters like effective tillers $hill^{-1}$filled grain $panicle^{-1}$, grain yield, straw yield, biological yield and 1000-grain weight except plant height and panicle length of BRRI dhan41 significantly responded to different levels of applied S.

Islam *et al*. (2009) conducted an experiment at the Department of Soil Science of Bangladesh Agricultural University (BAU), Mymensingh during T. *Aman* season of 2006 to evaluate the effects of different rates and sources of sulphur on the yield, yield components, nutrient content and nutrient uptake of rice (*cv.* BRRI dhan30). The grain and straw yields as well as the other yield contributing characters like effective tillers hill^{-1}, panicle length, filled grains panicle^{-1}and 1000 grain weight were significantly influenced due to application of sulphur. The highest grain yield of 5293 kg ha^{-1}and straw yield of 6380 kg ha^{-1}were obtained from 16 kg S ha^{-1} applied as gypsum. The lowest grain yield (4200 kg ha^{-1}) and straw yield (4963 kg ha^{-1}) were recorded with S control treatment. The overall results suggest that application of sulphur @ 16 kg S ha^{-1}as gypsum was the best treatment for obtaining higher grain yield as well as straw yield of T. *Aman* rice.

Rahman *et al.* (2007) conducted a field experiment on a non-calcareous dark gray floodplain soil (Sonatola series) of BAU farm, Mymensingh during *Boro* season of 2004 using rice (*cv.* BRRI dhan29) as a test crop. All plots received an equal dose of N, P, K and Zn. The application of S had a significant positive effect on tillers hill^{-1}plant height, panicle length and grains panicle^{-1}. The highest grain (5.81 t ha^{-1}), and straw (7.38 t ha^{-1}) yields were recorded in 20 kg S ha^{-1}. The control had the lowest grain yield of 4.38 t ha^{-1}as well as the lowest straw yield of 5.43 t ha^{-1}. Regression analysis showed that the optimum dose of S was 32.89 kg ha^{-1}and the economic dose of S was 31.59 kg ha^{-1} for maximizing the yield.

Lar Oo *et al.* (2007) studied on the effect of N and S levels on productivity and nutrient uptake in aromatic rice. Growth and yield attributes, grain, straw and biological yields increased significantly with N and S levels. The increase in grain yield due to application of 100 and 150 kg N ha^{-1}over control was 1.99 tones ha^{-1}and 1.95 tones and in terms of percentage increase was 49.5 and 48.5% respectively. The percentages increase in the grain yield of rice at application of 20, 40 and 60 kg S ha^{-1}over the control were in the order of 6.5, 7.3 and 8.8% respectively. Singh *et al.* (2005) performed a field experiment during the kharif season on an Inceptisol in Varanasi, Uttar Pradesh, India, to study the effect of S and Mn fertilizer application on the content and quality of bran oil of different rice cultivars, *viz.* Pant-12 (short duration), Swarna (long duration) and Malviya-36 (medium duration). The treatments comprised S and Mn applied at 0, 25, 50 and 0, 10, 20 kg ha^{-1} through gypsum and MnC_{l2}, respectively, and their combinations. A uniform application of recommended doses of N, P and K was given in all the experimental plots.

Application of both S and Mn significantly enhanced the bran content and yield of rice over the control. The highest dose of Mn and S on an average caused an increase of 15.2 and 45.0% in bran oil yield over the control, respectively. Increasing levels of S broughtabout noticeable increment in the percentage of unsaturated fatty acids, including PUFA indicating improvement in the quality of bran oil. Biswas *et al.* (2004) reported the effect of S in various region of India. The optimum S rate varied between 30-45 kg ha^{-1}. Rice yields increased from 5 to 51%. Across the crops and regions the agronomic efficiency varied from 2 to 27%. Peng *et al.* (2002) conducted a field experiment where one hundred and sixteen soil samples were collected from cultivated soils in Southeast Fujian, China. Field experiments showed that there was a different yield increasing efficiency with application S at the doses of 20-60 kg $ha^{-1}$to rice plant. The increasing rate of rice yield was 2.9-15.5% over control. A residual effect was also observed. Sarfaraz *et al.* (2002) carried out a field experiment to determine the effect of different S fertilizers at 20 kg ha^{-1}on crop yield and composition of rice *cv.* Shaheen Basmati in Pakistan. They found that the number of tillers m^{-2}, 1000-grain weight, grain, and straw yield were significantly increased with the application of NPK and S fertilizer compared to the control. Raju and Reddy (2001) studied the response of both hybrid and conventional rice to Sulphur (at 20 kg ha^{-1}) and Zinc (at 10 kg ha^{-1}) applications. Conventional rice, MTU 2067 out yielded the hybrid rice MUT-HR 2003 by 21%. Significant improvement in grain yield was observed due to sulphur application. Zinc application failed to improve the yield markedly. Vaiyapuri and Sriramachandrasekharan (2001) conducted an experiment on integrated use of green manure (3.5 t ha^{-1}) with graded levels of sulphur (0, 20 and 40 kg ha^{-1}) applied through three different sources in rice cv. ADT 37. They reported that the highestrice yield (5.3 t ha^{-1}) was obtained when green manure was applied along with pyrite at 20 kg S ha^{-1}which was comparable with pyrite applied at 40 kg ha^{-1} in the absence of green manure.

Poongothai *et al.* (1999) showed that application of 60 kg S ha^{-1}as gypsum along with green leaf manure at the rate of 6.25 t ha^{-1} increased the sulphur use efficiency, straw and grain yields of rice.

Sarkunan *et al.* (1998) carried out a pot experiment to find out the effect of P and S on the yield of rice under flooded condition on a P and S deficient sandy loam soil. Increasing levels of P from 0-100 mg kg^{-1} progressively increased the grain yield from

16.9 to 42.5 g pot^{-1}. Sulphur addition at 25 mg kg^{-1} resulted in 9% increase in grain yield. The treatment combination of 100 mg P and 10 mg S kg^{-1}soil gave significantly higher grain yield than the other treatments. Uddin *et al.* (1997) conducted a field experiment in Patuakali during *Aman* season of 1990 to see the effect of N, P, and S on the yield of rice *cv.* Haloi. They reported that application of 20 kg S ha^{-1}increased tillering, grains $panicle^{-1}$ and grain yield of rice. Sahu and Nandu (1997) carried out two field experiments, one in black soil and other in laterite soil to determine the response of rice *cv.* Jajati and Lalat to sulphur (0-60 kg ha^{-1}) in Orissa. They observed that mean grain yield increased with up to 40 kg S ha-1 onblack soil and the yield was the highest with 60 kg S ha^{-1}on the laterite soil. Gupta *et al.* (1997) conducted field experiments in the karif seasons of 1996 and 1997 at one Regional Agricultural Research Station, India to study the effects of sulphur sources sulphur powder, gypsum, iron pyrites and sulphur dose (0, 10, 20, 30 or 40 kg S ha^{-1}) on rice. They showed that compared with controls, rice grain yield increased by 14.2, 24.2, 25.6 and 20.1% with the four rates of sulphur respectively. The optimum dose was 20 kg S ha^{-1}. Islam *et al.* (1996) conducted field experiments during T. *Aman* season of 1992 to examine the response of BR11 rice to S, Zn and B. They found that application of 20 kgS ha^{-1} at both locations significantly increased the grain yield of rice. Islam *et al.* (1995) carried out a field experiment during *Aman* season of 1992 toinvestigate the response of BR31 rice to different nutrients including S. They reported that application of 20 kg S $ha^{-1}$with 100 kg N ha^{-1} increased the grain yield by 1300 kg N ha^{-1} application.

2.3. Zinc status in Bangladeshi soils

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

Bhuiyan *et al.* (1993) revealed that the productivity of rice and wheat alone is still low (around 2 t ha^{-1}) because of many constraints along with poor soil and micronutrient deficiencies in soils. Multiple micronutrient deficiencies (Zn, Mn, Cu, B and Mo) occur in soils of the Indo-Gangetic plains (IGP) and are becoming more frequent as cropping intensity increases. Low soil organic matter levels, little retention of crop residues and limited return of animal manures to soils intensify these deficiencies (Mondal *et al.*, 1992). Imamul *et al*. (2000) reported that increase of cropping intensity coupled with minimum use of fertilizer inputs are causing serious depletion both macro and micronutrients from soils. Thus, the micronutrients deficiencies (Zn, Mn, Cu, B and Mo) are becoming more in the region. Fifty four soil samples from ten districts of Bangladesh were studied for vertical distribution of DTPA extractable Zn, Cu, Fe and Mn and their relationship with some soil properties. As per critical limit prescribed for Zn and Fe, 44 and 20 percent of the soils could be rated as deficient in available zinc and iron respectively. Kalyanasundram and Mehta (2010) reported that there is possibility of an antagonistic relationship between zinc and phosphorus in soil and its contribution to phosphorus induced zinc deficiency. In some places in Bangladesh, rice crop loss due to zinc deficiency ranged from 10 to 80 % and about 1.21 million hectares of wetland rice soils are assumed to be zinc deficient.

2.4. Role of Zinc in plants

Zinc is essential in protein synthesis and gene expression in plants (Cakmak, 2008). It has been estimated that about 10% of the proteins in biological systems need Zn for their structural and functional integrity. This element has also been indicated to be required as a co-factor in over 300 enzymes. During germination, production of reactive oxygen species (ROS) is well known and Zn plays a central role in detoxification of ROS in plant cells. Zinc is one of the important micronutrient which is essential for plant growth. Plant roots absorb zinc as ion (Zn^{+2}). Zinc is closely involved in the diversity of enzymatic and N metabolism of plant. Zinc application to zinc deficient plant has been found to boost the growth of plants and yield of crop to a great extent. Zinc is the essential mineral element for protein synthesis (Dixit *et al*., 2012).

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

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

Zn plays very important role in plant metabolism by influencing the activities of hydrogenase and carbonic anhydrase, stabilization of ribosomal fractions and synthesis of cytochrome. Plant enzymes activated by Zn are involved in carbohydrate metabolism, maintenance of the integrity of cellular membranes, protein synthesis and regulation of auxin synthesis and pollen formation. Its deficiency results in the development of abnormalities in plants which become visible as deficiency symptoms such as stunted growth, chlorosis and smaller leaves, spikelet sterility. Micronutrient Zn deficiency can also adversely affect the quality of harvested products, plants susceptibility to injury by high light or temperature intensity and to infection by fungal diseases can also increase. (Hafeez *et al*., 2013). Kumar *et al*. (2016) conducted an experiment on *Phaseolus vulgaris* L., a micronutrient sensitive crop, which was grown in seven combinations of macro and micronutrients. The results suggested that on acidic soils, micronutrients application is indispensable forimproving growth and yield of crops, particularly pulses, which are more sensitive to micronutrients. Its supplement can also increase the plant's use efficiency of macronutrients (NPK) due to their improved recovery efficiency by plant.

2.5. Effect of zinc application on rice

2.5.1. Crop growth parameters

Khan *et al*. (2007) reported that, increasing the levels of Zn in soil significantly influenced growth in rice crop. The treatment receiving 10 kg Zn ha^{-1}significantly increased the plant height (74.38 cm) and maximum number of (17.41) tillers $plant^{-1}$. The minimum plant height (59.50 cm) was recorded in control. The increase in growth parameters might be assigned to adequate supply of zinc that might have increased the availability and uptake of other essential nutrients and there by resulting in the improvement of crop growth in rice. Rao (2003) reported that application of 30 kg $ZnSO_4$ ha^{-1}significantly increased the plant height on sandy clay loam soils of Varanasi. While, Chaudary and Sinha (2007) found that application of $ZnSO_4$ @ 50 kg ha^{-1}significantly increased the plant height on silty - clay soil of Pusa, Bihar. Ghoneim (2016) observed that methods of Zn application significantly affected the plant height. Maximum plant height of 100 cm was recorded from the treatment with 15 kg Zn ha^{-1}as soil application which differs significantly from the other treatments. Minimum plant height was recorded with T_1 (control). The application of different methods of Zn application significantly increased the tiller number over control. The increased of tiller number by soil application of Zn may be attributed due to increase of nutrients availability in soil compared with other treatments. Chaudhary and Sinha (2007) and Sriramachandrasekharan and Mathar (2012) reported that the highest (28.25 g hill^{-1}) and the lowest (7.28g hill^{-1}) dry matter was accumulatedin case of Zn_4 (6kg) and Zn_1 (0kg treatment at maturity and tillering respectively. Several researchers observed that soil application of zinc sulphate significantly enhanced dry matter production over no zinc application and (Channal and Kandaswamy, 1997). On the other hand, Raju *et al.* (1994) did not observe any significant increase in dry matter production with soil application of zinc sulphate @ 20 kg ha^{-1} on clay loam soil with available DTPA- extractable zinc status of 1.8 ppm in Rabi season at Maruteru of Andhra Pradesh. Muthukumararaja and Sriramachandrasekharan (2012) reported that maximum dry matter production of (2.98 g pot^{-1}) at tillering and (40.93 g pot^{-1}) at panicle initiation was obtained with application of 5 mg Zn kg^{-1} which was about 44 to 60% greater ascompared with the treatment that did not receive zinc. Boonchuay *et al*. (2013) observed that foliar application with 0.5% zinc sulfate spray at panicle initiation , booting and 1 week and 2 weeks after flowering showed significantly higher plant height (68.2cm), tillers plant^{-1} (17), plant dry matter (50.1 g plant^{-1}). The lowest was recorded in control where there was no foliar application (60.1cm), tillers plant^{-1} (10), plant dry matter (41.1 g plant^{-1}). Hossain *et al.* (2001) reported that the application of Zn in combination with B and Mo significantly produced the highest plant height (123cm), panicle length (24.4cm,). The lowest was observed in control which did not receive zinc application. Kabeya and Shanker (2013) studied that the treatment receiving 30kg $ZnSO_4$ ha^{-1} recorded the highest plant height (125cm), SPAD value (57) in rice. The highest strawdry matter (41g) and leaf dry matter (28g) was also obtained from this treatment, the lowest was obtained in control. Significantly increased plant height was observed with the application of $ZnSO_4$ @ 15 kg ha^{-1}on silty clay loam soil of Maharashtra (Chaphale and Badole, 1999). Malik *et al*. (2011) observed that the treatment receiving 300ppm Zn in rice recorded the highest length of shoot + root (117cm), spikelet (10.67cm), dry matter production of root (3.9g pot^{-1}), shoot (14.2g pot^{-1}) and the lowest height was observed at control. Application of

$ZnSO_4$ @ 75 kg ha^{-1} significantly increased the dry matter production (63.60 q ha^{-1}) on clay loam soils of Khandwa, M.P. (Tomar *et al*., 1994). Jena (1999) from a field experiment on clay loam soils of Bapatla reported that soil application of $ZnSO_4$ @ 50 kg $ha^{-1}$and seedling root dip in 2% ZnO significantly increased the dry matter production. Kulandaivel *et al*. (2004) reported that application of 30 kg $ZnSO_4$ along with 5 kg $FeSO_4$ ha^{-1} produced higher dry matter on sandy clay loam soils of New Delhi. Singh and Sharma (1994) noticed that basal dressing of all zinc carriers gave significantly higher tillers m^{-2} than foliar spray on silty clay soils of U.P. Whereas, Mustafa *et al.* (2011) conducted a field experiment at Faisalabad, Pakistan on Super basmati rice variety and noticed that basal application of 25 kg $ha^{-1}$of $ZnSO_4$ recorded more number of tillers m^{-2} (258) and it was at par with foliar application of 0.5% $ZnSO_4$ (254) at 15 DAT. Khan *et al.* (2003) reported that the maximum plant height (101 cm) was recorded from the treatment @ 10 kg Zn $ha^{-1}$by soil Zn application which did not differ significantly from that of foliar spray of 0.2% $ZnSO_4$ on alkaline calcareous soils of Pakistan. Sreenivasa Rao (2003) reported that on sandy clay loam soils of Bapatla, root dip plus foliar application of 0.5% $ZnSO_4$ significantly increased the plant height of rice.

Khanda *et al*. (1997) observed that foliar application of $ZnSO_4$ resulted in increased the dry matter production (9.05 t ha^{-1}) over no zinc application but it was on at par with soil application on sandy loam soils of Bhubaneswar. The maximum number of tillers m^{-2} (415.67) was recorded where zinc was applied @ 10 kg ha^{-1} by soil dressing which did not differ significantly from that of foliar spray of 0.20% $ZnSO_4$ and root dipping of 1.0% $ZnSO_4$ on silt loam soils at Pakistan as observed by Khan *et al.* (2003). Apoorva (2016) studied that the treatment receiving soil application of bio Zn @30 kg ha-1 recorded the plant height (100.6 cm), the highest number of tillers m^{-2} (440.0) followed by foliar application of 0.2 % Zn as $ZnSO_4$ over control treatment. A field investigation was carried out by Rahman *et al*. (2008) at Bangladesh Agricultural University, Mymensingh farm during 2004 *Boro* rice with seven treatments viz. T_1: S_0Zn_0 (control), T_2: $S_{10}Zn_0$, T_3: $S_{20}Zn_0$, T_4: $S_0Zn_{1.5}$, T_5: S_0Zn_3, T_6: $S_{10}Zn_{1.5}$, T_7: $S_{20}Zn_3$.

The experimental result indicated that, the height of *Boro* rice plant and plant tiller was significantly affected due to application S and Zn. Apparently, the tallest plant (96.58

cm) and the maximum tiller (12.1) was observed in $S_{20}Zn_3$, the recommended dose of S and Zn (BARC, 1997), which was superior to all other treatments. The shortest plant (84.95cm) and the lowest tiller (7.6) was recorded in S_0Zn_0 (control).

2.5.2. Yield and Yield contributing parameters

Naik and Das (2007) reported that the soil application of Zn @ 1.0 kg ha^{-1} as Zn-EDTA recorded highest grain yield of (5.42 t ha^{-1}), filled grain percentage (90.2%), 1000-grain $^{-1}$basal application of $ZnSO_4.7H_2O$. Ghoneim (2016) reported that the highest number of panicles m^{-2} was recorded in soil application of Zn followed by foliar application of Zn, while the minimum number of panicles m^{-2} rice plant was recorded in control. The number of spikelet's panicle^{-1}, percentage of filled grain and 1000-grain weight followed the same trend of response i.e. increased with different methods of Zn application compared to control but, no significant differences were found amongst the various methods. The highest grain yield of 9.60 tones ha^{-1} was recorded by soil application of Zn. No significant differences were observed in grain yield with root soaking or foliar. It is also observed that straw yield of rice significantly increased with different methods of Zn application (soil, root soaking or foliar application of Zn) compared with no zinc application, but, no significant difference were observed between Zn application methods.

Prasad *et al.* (2010) reported that the highest grain yield (4.35 t ha^{-1}) and straw yield of 7.27 t ha^{-1}) was recorded under 100% crop residue level and 10 kg Zn ha^{-1} in rice compared no zinc application treatment. Perusal of data revealed that minimum rice yield (7.09 t ha^{-1}) was recorded with absolute control plots where no application of zinc and sulphur was done during entire experimentation period. Whereas, corresponding maximum (7.63 t ha^{-1}) rice yield was recorded with combined application of 30 kg sulphur and 6 kg zinc (Ali *et al.*, 2012; Singh *et al.*, 2002). This combined analysis suggested that for better output and for balanced nutrition combined application is advocated. Mustafa *et al*. (2011) observed that Zn application had significantly pronounced effect ongrowth and yield of rice. Maximum productive tillers m^{-2} (249.80) and maximum grain yield (5.21 t ha^{-1}) were noted with basal application at the rate 25 kg ha^{-1}, 21 % $ZnSO_4$ and minimum productive tillers (220.28) and minimum grain yield (4.17 t ha^{-1}) was noted in foliar application at 75 DAT @ 0.5% Zn solution. Ram *et al.*

(2005) reported that maximum number of filled grains panicle-1 was observed with basal application of 20 kg $ZnSO_4$ ha^{-1}along with foliar spray of 0.5% $ZnSO_4$ three times, initiated from 20 DAT at 10 days interval on silty loam soils of Faizabad (U.P.). Hossain *et al*. (2001) reported that the application of Zn in combination with B and Mo significantly produced higher grain yield (4.7 t ha^{-1}), straw yield (7.07 t ha^{-1}) and 1000-grain weight (23.5g) in rice and the minimum recorded in control where no micronutrients were applied. Singh *et al*. (2012) observed that the maximum plant height (101.7cm), dry matter (28.25 g $hill^{-1}$) and grain yield (7.5 t ha^{-1}) ware recorded with application of Zn@ 6kg and minimum plant height (78.5cm), dry matter (7.8 g $hill^{-1}$) and grain yield (6.0 t ha^{-1}) ware seen in control. Boonchuay *et al*. (2013) observed that foliar application with 0.5%zinc sulfate spray at panicle initiation ,booting and 1 week and 2 weeks after flowering showed significantly higher grain weight (20.1g $plant^{-1}$), straw weight (30.1g $plant^{-1}$), panicles $plant^{-1}$ (13) and the lowest was seen in control where there was no foliar application.

Mustafa *et al*. (2011) conducted a field experiment at Faisalabad, Pakistan on Super basmati rice variety and reported t-hat basal application of 25 kg $ZnSO_4$ ha^{-1} of recorded more test weight and it remained at par with foliar application of 0.5% $ZnSO_4$ and root dip treatments with zinc solution. Trivedi *et al.* (1998) concluded that on clay soils of Gujarat, application of 11.2 kg $ZnSO_4$ ha^{-1} produced higher straw yield with the cultivar, Jaya than GR-11 during kharif season. A field investigation was carried out by Rahman *et al*. (2008) at Bangladesh Agricultural University, Mymensingh farm during 2004 with Boro rice having seven treatments viz. T_1: S_0Zn_0 (control), T_2: $S_{10}Zn_0$, T_3: $S_{20}Zn_0$, T_4: $S_0Zn_{1.5}$, T_5: S_0Zn_3, T_6: $S_{10}Zn_{1.5}$, T_7: $S_{20}Zn_3$. The experimental result indicated that, panicle length was significantly affected to S and Zn application. The highest Panicle length (25.26 cm) was obtained from S20Zn3 and the lowest (22.73 cm) is recorded in in S_0Zn_0 (control). The number of effective tillers $hill^{-1}$due to different treatments varied from 7.6 to 12.1. The weight of 1000 grains was not significant with various treatments. The 1000-grain weight followed the order $T_4>T_2>T_7>T_5>T_3>T_6>T_1$. 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. Asignificant and positive effect of S and Zn on straw yield of *Boro* rice was observed. The highest straw yield (7.32 t ha^{-1})

obtained in $S_{20}Zn_{1.5}$, the second highest in $S_{20}Zn_0$ (7.25 t ha^{-1}) and the lowest (5.47 t ha^{-1}) in S_0Zn_0. Abid *et al*. (2011) reported that the growth and rice yield were significantly enhanced by application of Zn, Fe and Mn either alone or in various combinations. The treatment comprising 10 mg each of Mn and Zn added per kg soil along with basal dose of NPK fertilizers proved to be the best combination. It is evident that the highest number of grains panicle $^{-1}$ (118.66), 1000 grain weight (23.93g) and maximum paddy yield (78.73 g) was recorded by treatment (NPK+Mn+Zn) and minimum yield (20.53 g) was recorded in (control). It was probably due to the more balanced nutrient ratio, which improved the yield and yield contributing characteristics of rice Shivay *et al*. (2015) observed that application of 5 kg Zn ha^{-1}(soil) + 1 kg Zn ha^{-1} (foliar) recorded the highest grain yield (4.52 t ha^{-1}), straw yield (8.12 t ha^{-1}), tillers m^{-2} (342), grains panicle^{-1}(94), 1,000 grain weight (22.7g) which was significantly more than soil application of ZnS or Zn-coated urea (ZnCu), which in turn was significantly superior to foliar application of ZnS. Sharma *et al*. (1999) reported that soil application of 36 kg $ZnSO_4$ ha^{-1}produced significantly higher effective tillers m^{-2} on clay loam soils of Rajasthan. It was observed that the highest mean values of yield and its components i.e. panicle weight (2.38g), number of filled grains panicle^{-1} (112.73), number of panicles m-2 (482.2), 1000 grain weight (22.15g), grain yield (3.80 tons ha^{-1}), straw yield (5.05 tons ha^{-1}), were recorded by treatment (soil + foliar) of Zn in combination with 50 % Mineral N+ 50 % organic N (Gomaa *et al*., 2015). Khan *et al*. (2007) reported that, increasing the levels of Zn in soil significantly influenced yield and yield components of the rice crop. The treatment receiving 10 kg Zn ha^{-1}significantly increased maximum number of panicles plant^{-1}(15.88) and spikelet's panicle-1(86.48). The highest grain yield of (101.80 g pot^{-1}) and straw yield (140.40 g pot^{-1}) was recorded in treatment receiving 10kg Zn ha^{-1}which was statistically at par with the treatment receiving 15 kg Zn ha^{-1}. The minimum grain yield (73.90 g pot^{-1}), straw yield (102.28 g pot^{-1}) was recorded in control. The increase in yield parameters might be ascribed to adequate supply of zinc that might have increased the availability and uptake of other essential nutrients and there by resulting in the improvement of crop growth in rice. Lowland rice responded significantly to applications of Zn, Cu, B, Mo, Mn and Fe .The adequate rates of micronutrients for maximum grain yield were Zn 33 mg kg^{-1}, Cu 25 mgkg^{-1}, B 26 mg kg^{-1}, Mo 10 mg kg^{-1}, Mn 250 mg kg^{-1}, and Fe 1269 mg kg^{-1}. In addition to grain yield, straw yield, panicle density, and root growth of lowland rice were also improved with the addition of most of these micronutrients (Fageria, 2004). Sinha (2007) noticed that combined application of 120 kg N together with 25 kg $ZnSO_4$ha-1 resulted in significantly higher effective tillers m^{-2} on silty-clay soil of Pusa, Bihar. Kumar *et al.* (2016) found that application of 20 kg $ZnSO_4$ ha^{-1} incubated or blended either with press mud or FYM produced significantly higher number of filled grains $panicle^{-1}$, but, it was at par with the application of 40 kg $ZnSO_4$ ha^{-1} alone on sodic soils of U.P. Mustafa *et al.* (2011) conducted a field experiment at Faisalabad, Pakistan on Super basmati rice variety and reported that basal application of 25 kg $ZnSO_4$ ha^{-1} recorded more test weight and it remained at par with foliar application of 0.5% $ZnSO_4$ and root dip treatments with zinc solution. Jena (1999) noticed significant increase in grain yield with the soil application of 50 kg $ZnSO_4$ ha^{-1} on clay loam soils of Bapatla. Similarly, increased grain yield was recorded with application of $ZnSO_4$ @ 20 kg ha^{-1} in coastal area of Bhubaneswar (Katyal and Gangwar, 2000). While, Channabasavanna *et al.* (2001) observed that on deep black soils of Siriguppa (Karnataka), application of $ZnSO_4$ @ 25 kg ha^{-1} significantly increased the grain yield. Similar result was also obtained with the application of 50 kg $ZnSO_4$ ha^{-1} in red loam soil of Bhavanisagar (Sankaran *et al.*, 2001). Kulandaivel *et al.* (2003) noticed that application of 30 kg $ZnSO_4$ ha^{-1} along with 10 kg FeSO4 ha^{-1} produced significantly higher straw yield on loamy soil of New Delhi.

Application of N along with Zn increased grain yield and grain-to-straw ratio significantly. Ammonium sulfate used as N source along with Zn gave significantly higher yield as 25% in grain and 14 % in straw and the highest grain-to-straw ration compared to all other treatments. It was possibly due to availability of more Zn and more number of filled grains under reduced pH. Application of zinc along with N had synergistic effect on N and Zn uptake in rice. (Rahman *et al.*, 2002). Kumar and Singh (2006) conducted a trial on a silty loam soil and reported that foliar application with 0.5% $ZnSO_4$ at three weeks after transplanting recorded higher number of productive tillers m^{-2} but it was on a par with soil application and root dip treatments. Ravikiran and Reddy (2004) found that foliar spray of Zn increased number of productive tillers from control to 0.5 % Zn spray followed by soil application but the highest increase was noticed with 0.5% spray only. An investigation was conducted by Alam and Kumar (2015) at the Agricultural Farm in NewajiTola in Saran district of Bihar, India to evaluate the effect of Zinc on growth and yield of rice var. The experiment was laid out in a randomized complete block design (RCBD) 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} $ZnSO_4$) and four replications. The result revealed that the maximum panicle length (23.39 cm), the maximum number of effective tillers m^{-2} (317) ware 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 1000 grain weight (24.97 g) was obtained from 10 kg ha^{-1} $ZnSO_4$ and the minimum 1000 grain weight (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 qha^{-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} $ZnSO_4$. The plant height and grain yield of rice, significantly increased at 1% and 2 % zinc concentrations, compared with those of zero zinc (control).At the rate of 0.5 % zinc, also an increase was obtained but not significant. A positive correlation was found between zinc concentration and the rice growth and yield. Number of tillers and panicle length was also non-significantly increased by zinc application. The application of Zn at rates as high as 10 mgkg^{-1} soil increased the height and improved the yield-contributing characters and the shoot, straw, and grain yields in IR28; it has no effect in IR10198-66-2. In general, the shoot, straw, and grain yields were higher in IR10198-66-2 than in IR28 (Korayem*et al*. 1993). Manas *et al*. (2017) reported that the zinc contents and uptake in rice plant at maturity, significantly was influenced by various levels of zinc application. The higher concentration of Zn in grain, husk and straw was showed at 7.5 kg Zn ha^{-1} followed by 5.0 kg Zn ha^{-1} application. The magnitude of Zn concentration was found in an order; straw (88.32-124.77 mg kg^{-1})>grain (23.20-34.27 mg kg^{-1}) >husk (20.37-30.80 mg kg^{-1}). Ram *et al*. (1995) observed the maximum filled grains panicle were with the treatment that received combined application of 20 kg $ZnSO_4$ ha^{-1} as basal + three sprays of 0.5% $ZnSO_4$ solution, but it was at a par with separate application of $ZnSO_4$ as soil and foliar spray on partially reclaimed sodic soil at Faizabad, U.P. There was no significant impact on 1000-grain weight of rice by zinc application methods (basal and foliar spray) on a partially reclaimed sodic soil at Faizabad as observed by Reddy *et al*. (2011). Sharma *et al*. (1999) observed the highest grain yield with soil application of 36 kg $ZnSO_4$ ha^{-1}

which did not differ significantly with that of two sprayings of $ZnSO_4$ @ 0.5% twice at 30 and 45 DAT on clay loam soils of Rajasthan. It was observed that the highest mean values of yield and its components, number of panicles m^{-2} (446.6), the number of filled grains panicle^{-1} (13.3), the highest grain yield (5355 kg ha^{-1}). The highest straw yield (6347 kg ha^{-1}) were recorded by the treatment receiving RDF +Soil application of bio Zn @30 kg ha^{-1} which was at par with RDF +foliar application of 0.2 % Zn as $ZnSO_4$ and RDF +foliar application of 1 ml Zn as nano zinc (Apoorva, 2016). Dixit *et al*. (2012) observed that application of Zn at 25kg ha^{-1} in rice significantly increased the panicle length(24.96 cm), protein content (11.56%), grain yield (60.34 q ha^{-1}), straw yield (77.37 q ha^{-1}) with significant difference from than that of plant grown without Zinc treatment. Keram *et al*. (2012) recorded that the highest grain (3.88 t ha^{-1})and straw (4.76 t ha^{-1}) yield as were observed in treatment consisting NPK+20 kg Zn ha^{-1} compared to NPK alone. This study was conducted by Maqsood *et al*. (2008) at agronomic research area, University of Agriculture, Faisalabad, during kharif 2008 to evaluate the effect of different methods and timing of zinc application on growth and yield of rice. Experiment was comprised of eight treatments *viz.,* control, rice nursery root dipping in 0.5 % Zn solution, $ZnSO_4$ 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, and kernel yield and harvest index. Maximum productive tillers m^{-2} (249.80) was noted with basal application at the rate 25 kg ha^{-1} and minimum (220.28) were recorded with foliar application at 60 DAT @ 0.5 % Zn solution. Zinc application methods and timing had significantly pronounced effect on paddy yield. Maximum rice yield (5.21 t ha^{-1}) was achieved in treatment Zn (Basal application at the rate of 25 kg ha^{-1} and minimum paddy yield (4.17 t ha^{-1}) was noted in Zn (foliar application at 75 DAT @ 0.5% Zn solution). Zinc application increases the crop growth rate of rice. A field experiment was conducted by Khan *et al*. (2003) where comparative effect of three different methods of zinc application was studied, aimed at alleviating Zn deficiency in transplanted flood rice (*cv.* IRRI-6) grown in alkaline soil. Three methods were tried i.e. nursery root dipping in 1.0% $ZnSO_4$,0, 20% $ZnSO_4$ Solution spray after transplanting and 10 g Zn ha^{-1} by field broadcast method. The yield and yield parameters increased significantly by the application of Zn by any method. Among the methods the effect of Zn was non-significant on yield components like tiller m^{-2}, spikelet's panicle^{-1}, % filled grains, 1000-grain weight and straw yield. However, soil application of Zn@10 kg ha^{-1} was rated superior because it produced significantly higher paddy yield. Khatun *et al.* (2018) conducted a field experiment was at the Agronomy Research Field, Department of the Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh during *Aman* season to evaluate the growth, yield and yield attributes of aromatic rice (*cv.* Tulshimala) under the fertilization of cow dung (organic manure) and zinc (micronutrient). The application of different levels of cow dung and zinc fertilizers considerably increased the number of total tillers hill^{-1}, number of productive tillers hill, panicle length, test weight (g), grain yield hill^{-1} (g), straw yield hill^{-1}(g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), and biological yields over control. However, the treatment combination of CD_1Zn_2 i.e. 10 t ha^{-1} cow-dung and 12 kg ha^{-1} $ZnSO_4$ along with other recommended doses of inorganic fertilizers produced the highest grain yield (2.79 t ha^{-1}) and strawyield (5.80 t ha^{-1}) over other treatments.

Ghasal *et al*. (2018) carried out a two-year field study to assess the effect of Zn application on Zn content and uptake at several growth stages and in several parts of the rice kernel: hull, bran, and the white rice kernel. Variety 'PB 1509' with1.25 kg Zn ha^{-1} as Zn-EDTA + 0.5% foliar spray at maximum tillering (MT) and panicle initiation (PI) stage registered the highest Zn content hull, bran, and the white rice kernel. The variety 'PB 1401' showed the highest Zn uptake in rice straw, while 'PB 1509' showed the highest Zn uptake in hull and white rice kernel. Application of 1.25 kg Zn ha^{-1} (Zn-EDTA) + 0.5% foliar application at MT and PI and 2.5 kg Zn ha^{-1} $ZnSO_4.7H_2O$ (Zn-SHH) + 0.5% foliar application at MT and PI resulted in higher Zn uptake than other treatments. Zn-EDTA along with 0.5% FS, despite the application of a lower quantity of Zn leading to the highest Zn mobilization efficiency index and Zn-induced nitrogen recover efficiency, produced the highest kernel yield.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted to find out the influence of sulphur and zinc on growth and yield of BRRI hybrid dhan2. Materials used and methods followed during the course of study have been mentioned in this chapter under the heads and sub-heads as follows.

3.1. Description of the experimental site

3.1. 1. Experimental period

The experiment was conducted during the period from December, 2019 to May, 2020.

3.1.2. Experimental location

The present experiment was conducted in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The location of the site is 23.077' N latitude and 90.035' E longitude with an elevation of 8.2 meter from sea level. Experimental location has been 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). The maximum temperature during the crop growth period ranged from 15^{0C} to $35^{0\ C}$ with an average of $28.5^{0\ C}$ during 2019-2020, while the minimum temperature ranges was from $10^{0\ C}$ to $24^{0\ C}$ with an average $17.33^{0\ C}$. The mean relative humidity ranged from 57 percent to 74 percent. The total rainfall received during the crop growth period was 245 mm received in 18 rainy days. Details of the meteorological data of air temperature, relative humidity, rainfall and sunshine hour during study period has been presented in Appendix II.

3.1.4. Soil

The soil of the experimental field belongs to “The Modhupur Tract”, AEZ-28 (FAO, 1988). Top soil was silty clay in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. The experimental area was well irrigated with pacca drainage system and situated above flood level. The soil was sandy loam with organic matter 1.15%, 26% sand, 43% silt and 31% clay. The soil is slightly acidic in reaction with low organic matter content. The experimental area was above flood level and sufficient sunshine having available irrigation and drainage system during the experimental period. The experimental plot was high land having pH 5.6. The Details morphological, physical and chemical properties of the experimental field soil are presented in Appendix III.

3.2. Experimental details

3.2.1. Genetic (planting) material

Rice variety, BRRI hybriddhan2 was used as the test crops in this experiment.

3.2.2. Treatment of the experiment

The experiment consisted of two factors:

Factor A: Levels of S (4 levels) as

i. S_0: 0 kg S ha^{-1}(control)

ii. S_1: 20 kg S ha^{-1}

iii. S_2: 30 kg S ha^{-1}

iv. S_3: 40 kg S ha^{-1}

Factor B: Levels of Zn (4 levels) as

iZn_0: 0 kg Zn ha^{-1}(control)

ii. Zn_1: 3.0 kg Zn ha^{-1}

iii. Zn_2: 4.5 kg Zn ha^{-1}

iv. Zn_3: 6.0 kg Zn ha^{-1}

There were total 16 (4×4) combination as a whole *viz.*, S_0Zn_0, S_0Zn_1, S_0Zn_2, S_0Zn_3,S_1Zn_0, S_1Zn_1, S_1Zn_2, S_1Zn_3, S_2Zn_0, S_2Zn_1, S_2Zn_2, S_2Zn_3, S_3Zn_0, S_3Zn_1, S_3Zn_2 and S_3Zn_3.

3.2.3. Experimental design and layout

The two factors experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. There were 16 treatment combinations. The total numbers of unit plots were 48. An area of 600 m^2 (24.5 m × 18.1 m) was divided into 3 blocks and 48 unit-plots. The size of the each unit plot was 4.0 m × 2.5 m. The space between two blocks, and two unit- plots were maintained 1.0 m and 0.5 m, respectively. Adjacent unit-plots were separated by raised border. The 16 treatment combinations were assigned in the units according to design of plot.

3.3. Growing of crops

3.3.1. Seed collection and sprouting

Seeds of BRRI hybriddhan2 were collected from BRRI (Bangladesh Rice Research Institute), Gazipur 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 18th 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 15th 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 were mixed with the soil of each unit plots. The fertilizers N, P, K, S, Zn and B was applied in the form of urea, TSP, MoP, Gypsum, zinc sulphate and borax, respectively. Urea, TSP, MoP, Gypsum and borax were applied @ 80, 60, 90, 12 and 10 kg ha^{-1} (BRRI, 2016). S and Zn were applied as per treatment. The entire amount of TSP, MP, gypsum, zinc sulphate and borax were applied during final land preparation. Urea was applied in three equal installments as top dressing at early and maximum tillering and panicle initiation stages.

3.3.4. Transplanting of seedling

Seedlings were carefully uprooted from the nursery bed and transplanted on 23th

December, 2019 in well puddled plot with spacing of 20 × 15 cm. One healthy 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.

3.3.5. 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.

3.3.6.1. 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.

3.3.6.2. 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.

3.3.6.3. Insect and pest control

Furadan were applied at 15 DAT in the plot. Leaf roller (*Chaphalocrosis medinalis*) was found and used Malathion @ 1.12 L ha-1 at 25 DAT using sprayer but no diseases infection was observed in the field.

3.4. Harvesting, threshing and cleaning

The crop was harvested at full maturity based on variety when 80-90% of the grains were turned into straw color. 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 12% moisture content. Yields of rice grain and straw were recorded from each plot.

3.5. Data recording

Biometrical data were recorded on growth, development, yield attributes and yield. Different parameters were recorded at different well defined physiological stages *viz.*, tillering, panicle initiation (PI) stage, anthesis and maturity. These stages are critical stages for growth and development as well as realization of final output.

Tillering

Tillers are initiated at the base of the plant, emerging from the inside of the seedling leaves on the main shoot As rice enters the 3- to 4-leaf stage, tiller (or stool) formation typically begins, initiating the tillering stages (35 days). Tillers appear as secondary shoots to the main shoot.

Panicle Initiation (PI)

Panicle initiation (60 days) is the first stage in the reproductive phase of growth. It is determined when the panicle premordia initiate the production of a panicle in the uppermost node of the culm. At this point, the developing panicle is microscopic in size inside the stem and is not visible to the naked eye.

Anthesis or Flowering stage

The flowering stage (85 days) begins with the emergence of the first anthers from the uppermost spikelets on each panicle.

Maturity

The grain is mature, or ripe, when the endosperm becomes hard and opaque. While the grains ripen, the leaves of the plant begin to turn yellow as nitrogen is transferred from the leaves to the seed. The full maturity stage (110 days) is reached when more than 90% of the grains in the panicles have ripened.

Growth data

3.5.1 Plant height

The height of plant was measured in centimeter (cm) from the ground level to the tip of the plant at the afore-mentioned four stages. Data were recorded as the average of 5 plants selected at random from the inner rows of each plot.

3.5.1 Tillers hill^{-1}

Number of tillers hill^{-1} was recorded at the afore-mentioned stages as the average of randomly selected 5 plants from the inner rows of each plot.

3.5.1 Leaves hill^{-1}

The number of tillers hill^{-1} was counted at first at the afore-mentioned four stages. Only those tillers having three or more leaves were used for counting.

3.5.1 Sampling

Data pertaining to dry matter accumulation and LAI were taken through destructive sampling method. Five sample hills were uprooted from each plot at different stages and roots were removed. Hills were selected from third rows during sampling to minimize the border or side effect.

3.5.1 Leaf area index

Then uprooted plant hills were partitioned into green leaf, dead leaf, stem (culm + leaf sheath) and panicles. Leaf area was measured manually measuring the length and width of leaf and multiplying by a factor 0.75 as suggested by Yoshida (1981) just after removal of leaves to avoid rolling and shrinkage, and were transformed into leaf area index (LAI) according to Yoshida (1981).

3.5.1 Dry matter accumulation

The segmented plant samples were kept in separated envelopes and were oven dried at 70^0C for 72 hours. After drying, weight of each component was determined with a digital balance and the mean were calculated. Finally total dry matter (TDM) at different stages was calculated adding the weight of different plant parts.

3.5.1.1. Flag leaf chlorophyll content (SPAD value)

Flag leaves SPAD values were recorded at 7 days after flowering (DAF) using chlorophyll meter (Minolta-52, Japan) from each plots.

Yield data

3.5.2. Effective tillers (panicles) hill^{-1}

The total number of effective tillers hill^{-1} was counted as the number of panicle bearing tillers during harvesting. Data on effective tillers hill^{-1} were counted from 5 selected hills and average value was recorded.

3.5.2. Ineffective tillers hill^{-1}

The total number of In-effective tillers hill^{-1} was counted as the number of non-panicle bearing tillers during harvesting. Data on non-effective tillers hill^{-1} were counted from 5 selected hills and average value was recorded.

3.5.2. Panicle length

The length of panicle was measured with a meter scale from 5 selected panicles and the average length was recorded as per panicle in cm.

3.5.2. Filled grains panicle^{-1}

The total numbers of filled grains were collected randomly from selected 5 panicle of a plot on the basis of grain in the spikelet and then average numbers of filled grains panicle^{-1} was recorded.

3.5.2. Unfilled grains panicle^{-1}

The total numbers of unfilled grains was collected randomly from selected 5 plants of a plot on the basis of not grain in the spikelets without grain and then average numbers of unfilled grains panicle^{-1} was recorded.

3.5.2. Total grains panicle^{-1}

The total numbers of grains was calculated by adding filled and unfilled grain from selected 5 plants of a plot and average numbers of grains panicle^{-1} was recorded.

3.5.2. Weight of 1000-grains

One thousand grains were counted randomly from the total cleaned harvested grains and then weighed in grams and recorded.

3.5.2. Grain yield

Grains obtained from each unit plot were sun-dried and weighed carefully. Dry weight of grains of each plot were taken and converted to ton per hectare (t ha^{-1}).

3.5.2. Straw yield

Straw obtained from each unit plot were sun-dried and weighed carefully. Dry weight of straw of each plot were taken and converted to ton per hectare (t ha^{-1}).

3.5.2. 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.

3.5.2. Harvest index

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

$$HI = \frac{\text{Economic yield (grain weight)}}{\text{Biological yield (total dry weight)}} \times 100$$

3.6. Statistical Analysis

The data obtained for different characters were statistically analyzed to observe the significant difference among different treatments. The analysis of variance of all the recorded parameters was performed according to the procedure outlined by Gomez and Gomez (1984), using the MSTAT-C version 2.1 (Michigan State University, USA) statistical package design software. The difference of the means value was separated by Least Significance Difference (LSD) Test at 5% level of probability.

CHAPTER IV

RESULTS AND DISCUSSION

The influence of different doses of sulphur and zinc nutrients on yield contributing traits and yield of BRRI hybrid dhan2 were studied at the Research Farm of SAU, Dhaka. Results obtained were discussed under appropriate sub heads with suitable tables and graphs presented in proper format. The data on growth, yield and yield contributing characters of BRRI hybrid dhan2 are shown in graph 1 to 4 and tables 1 to 9. Yield and yield contributing characters include plant height, tillers hill^{-1}, leaf area index, dry matter accumulation, SPAD values of flag leaf, panicles hill^{-1}, dry-matter translocation into shoot, panicle length, filled grains panicle^{-1}, total weight of 1000-grains, grain yield, straw yield, and biological yield and harvest index.

4.1. Plant height

Plant height is one of the important growth and development indicators. Critical appraisal of data showed that plant height of rice was significantly affected by both the nutrients (sulphur and zinc) during different DAT; however the magnitude was not same for particular levels and it was increased with the advancement of growth up to anthesis and then after it was slowed down considerably (Fig. 1). Application of sulphur at the rate 20 kg ha^{-1} produced significantly taller plants over no application of sulphur (S_1) in all the treatments 35days after transplanting. Application of sulphur at the rate of 30 kg ha^{-1} showed superiority over S_1 and S_2 treatments at all DAT but produces at par with highest level of sulphur application i.e. 40 kg ha^{-1}. At maturity, plots treated with sulphur at 40 kg ha^{-1} produced the tallest plant (97.3 cm). Similar type of response was also noticed in case of zinc application. Application of Zn at 4.5 kg ha^{-1} recorded significantly higher plant height over no application of Zn, however it produces at par with Zn applied at 6 kg ha^{-1} (Zn_6 treatment) during entire life cycle (Fig. 2). Maximum plant height (101.7 cm) at maturity was recorded with application of 6 kg ha^{-1} (Zn_6 treatment), whereas corresponding minimum plant height (78.5 cm) was recorded with no application of Zn.

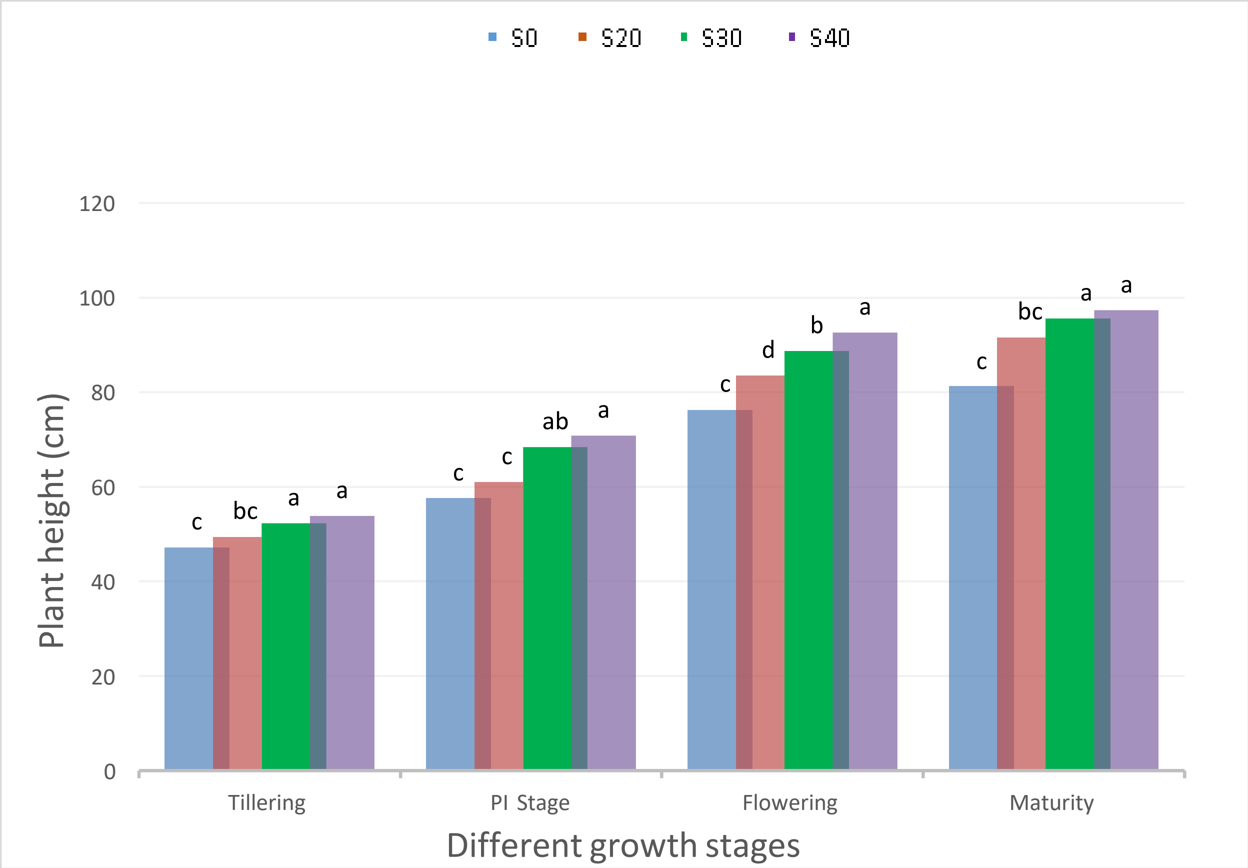

Fig. 1. Effect of sulphur on plant height at different phenological stages (DAT) of BRRI hybrid dhan2

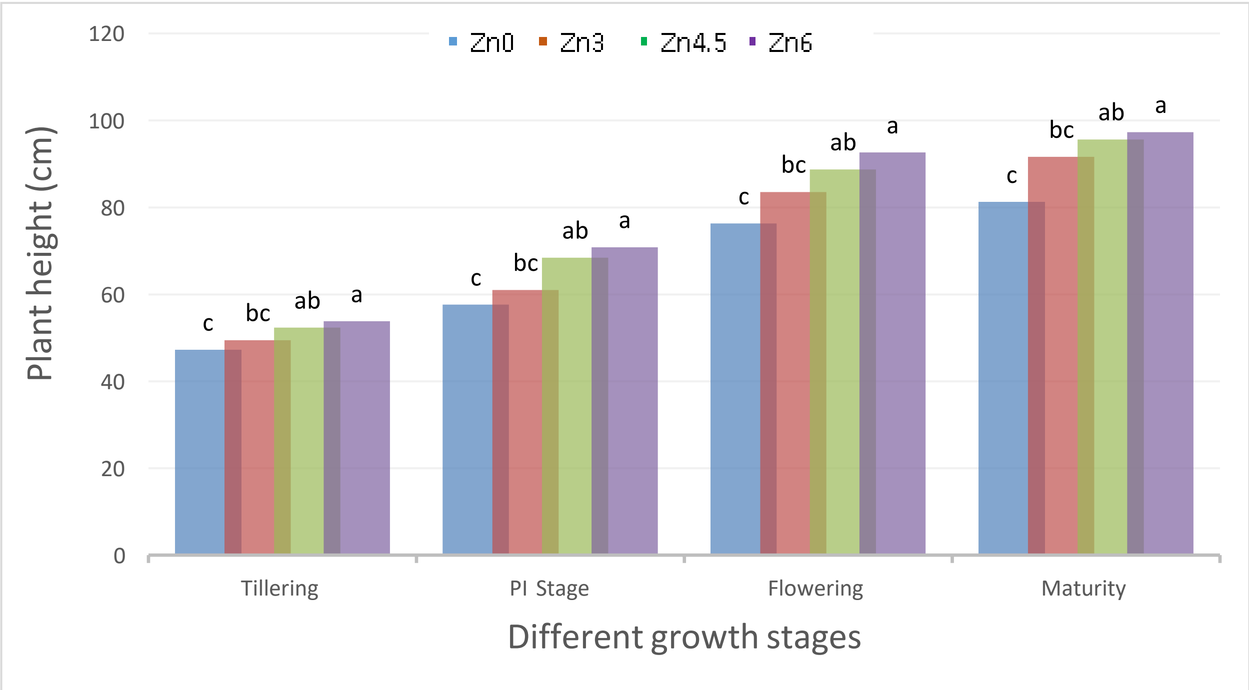

Fig. 2. Effect of zinc on plant height at different phenological stages (DAT) of BRRI hybrid dhan2

4.2. Number of tillers

Sulphur levels had significant influence on number of tillers as recorded at 60, 85 DATand at harvest stages (Table 1). As the sulphur levels was increased from 0 kg S ha^{-1} to 40 kg S ha^{-1}, the number of tillers increased significantly and recorded maximum (119.58tillers running m^{-1}) at 60 DAT and thereafter it subsequently declined. However, at 35 DAS sulphur level failed to brings significant variations in number of tillers. This may bedue to mutual competition among the plants for light, nutrients and other growth input resulting in mortality of tillers after 60 DAS. The highest tillers per running meter at 60 DAS might be due to higher availability of nutrient which facilitated propersynchronized tillering. These results are in close accordance to those of Yosef Tabar (2012); Alam *et al.*, (2015) and Puteh *et al.* (2014). The maximum number of tillers (77.33 running m^{-1}) was obtained with application of 40 kg S ha^{-1} (S_3). This was might be due to the fact that the number of tillers at this level of sulphur was so high that even after mortality, it remained significantly higher than that of other levels of sulphur and this consequently led to more number of panicle bearing tillers and panicle at this type of sulphur management. Similar findings was also reported by Devi and Sumathi (2013).

Table 1: Effect of S levels and Zn application on number of tillers (yield running m^{-1}) in BRRI hybrid dhan2

Treatments	Tillering 35 DAT	PI stage 60 DAT	Flowering (85 DAT)	Maturity (110 DAT)
S_0	47.25	99.26c	59.92c	53.75b
S_{20}	49.67	105.67b	67.90bc	61.50b
S_{30}	53.08	110.50b	72.83ab	70.92a
S_{40}	50.50	119.58a	80.08a	77.33a
Lsd $_{(0.05)}$	NS	6.25	10.89	9.34
Zn_0	41.92	98.01c	58.42b	55.50c
Zn_3	47.50	120.67a	75.75a	72.33a
$Zn_{4.5}$	46.92	106.58b	73.41a	70.25ab
Zn_6	52.17	109.75b	72.45a	65.42b
Lsd$_{(0.05)}$	NS	7.56	6.97	5.66
CV%	6.71	6.24	7.58	8.16
S X Zn	NS	S	NS	S

Within a column, values followed by the same letter (s) are not significantly different at 5% level of probability as per LSD test.

The number of tillers per running meter was significantly influence by zinc application (Table 1). Number of tillers at 35 and 85 DAT was recorded non-significant. The maximum tillers (72.33) were observed with 3 kg ha^{-1} zinc (Zn_3 treatment). These may be due to contribution of zinc in plant growth.

4.3. Leaf area index (LAI)

Sulphur application influences leaf area index (LAI) significantly. LAI increases with advancement of growth stage till the anthesis. Marked reduction in LAI was noticed at maturity for both the tested nutrients. Application of sulphur at 40 kg ha^{-1} produced the highest LAI (4.17) at anthesis. Similar result was reported by Sahaa *et al.*, 2007. Plots received 20 kg sulphur produced significantly higher LAI over no application and produced at par with other tested levels of sulphur in most of the stages (Table 2). Marked response of applied zinc on LAI was also noticed and it was more pronounce than sulphur treatments in general. In case of zinc application the highest LAI (4.29) was obtained with zinc at 6 kg ha^{-1} and minimum (3.89) with no application of sulphur (S_0) at anthesis. However lower LAI was notice during 35 days after transplanting. Results showed that the treatment ($Zn_{4.5}$) consisting of zinc at 4.5 kg ha^{-1} produced significantly higher LAI (4.13) over no application of zinc and at 3 kg ha^{-1} (Zn_3 treatment), however it produced at par with zinc applied at 6 kg ha^{-1}. This result is in agreement with Charati and Malakouti, 2006.

Table 2. Effect of sulphur and zinc nutrition on leaf area index (LAI) at different DAT

Treatments	Tillering 35 DAT	PI stage 60 DAT	Flowering (85 DAT)	Maturity (110 DAT)
S_0	2.26d	3. 35c	3.66b	3.31b
S_{20}	2.41c	3.48bc	3.85ab	3.54a
S_{30}	2.50b	3.76ab	3.94ab	3.69a
S_{40}	2.57a	3.81a	4.17a	3.52a
$Lsd_{(0.05)}$	0.06	0.32	0.35	0.18
CV%				
Zn_0	2.27c	3.51d	3.89c	3.17b
Zn_3	2.51b	3.73c	4.05b	3.29b
$Zn_{4.5}$	2.60ab	3.91b	4.13ab	3.71a
Zn_6	2.65a	4.16a	4.29a	3.56a
$Lsd_{(0.05)}$	0.13	0.17	0.21	0.15
CV%	8.21	7.59	9.87	6.43
S x Zn	NS	NS	NS	NS

Within a column, values followed by the same letter (s) are not significantly different at 5% level of probability as per LSD test.

4.4. Dry matter accumulation

Dry matter accumulation is important for the growth and development of any crop. The impact of sulphur and zinc on dry matter accumulation and at different DAT were presented in Table 3. Critical assessment of the data revealed that sulphur had significant effects on dry matter accumulation during all the DAT. Application of sulphur at 30 kg proved superior or at par with corresponding lower and higher dose, though the pattern of response was not similar for all the DAT. At maturity the range of response was limited and it was recorded minimum (25.71 g hill^{-1}) to maximum (27.65 g hill^{-1}). In case of zinc it was noticed that the highest (28.25 g/hill) and the Lowest (7.28 g hill^{-1}) dry matter was accumulated in case of Zn6 (6 kg) and Zn0 (0 kg) treatments at maturity and tillering, respectively (Chaudhary *et al.*, 2007).

Table 3. Effect of sulphur and zinc nutrition on dry matter accumulation in BRRI hybrid dhan2

Treatments	Tillering 35 DAT	PI stage 60 DAT	Flowering (85 DAT)	Maturity (110 DAT)
S_0	7.57b	18.41b	22.19b	25.71b
S_{20}	7.89b	18.77b	23.41b	26.77ab
S_{30}	8.21a	19.98a	25.17a	27.16ab
S_{40}	8.27a	20.18a	26.23a	27.65a
$Lsd_{(0.05)}$	0.53	1.37	1.59	1.74
CV%				
Zn_0	7.28c	18.96c	21.52c	24.89b
Zn_3	7.69bc	19.77b	22.54bc	25.52b
$Zn_{4.5}$	8.17ab	20.08ab	26.09a	27.57a
Zn_6	8.54a	20.73a	24.02b	28.25a
$Lsd_{(0.05)}$	0.51	0.72	1.61	1.21
CV%	9.27	8.74	9.50	10.24
S x Zn	NS	NS	NS	NS

Within a column, values followed by the same letter (s) are not significantly different at 5% level of probability as per LSD test.

4.5. Dry matter translocation into shoot

To know the efficient sink to source relation, pattern of dry matter translocation during different DAT were studied. It was recorded that dry matter share of root was maximum at tillering (35 DAT) and it was more than 15% across the levels of sulphur and zinc except at S_0 (0 kg) treatment where it was 20.9% (Table 4). Gradually diversion of photosynthetate was more towards shoot and maximum at the time of maturity. At maturity (110 DAT) minimum (86.7%) and maximum (90.2) dry matter was translocated to shoot with 0 kg and 40 kg sulphur application (Singh *et al.*, 2011). Across the DAT, anthesis (60 days) was proved most crucial stage and a launching pad for realization of seed production, as it was evident from translocations of photosynthate, which was within a narrow range (86.4 to 88.1%). Considerable variation was recorded at the time of maturity prove the importance of both the tested minerals rice production (Sahaa *et al.,* 2007). Sulphur prove crucial when it matter most, maximum (90.2%) was recorded with 40 kg S application, moreover, minimum (86.7%) was noticed in case of plot treated with 0 kg sulphur. This result is insignificance with Rahman *et al.*, 2008. Critical appraisal of data showed that zinc treatments had the little effect on dry matter translocation (%) into the shoot at anthesis and maturity.

Table 4. Effect of sulphur and zinc nutrition on dry matter translocation (%) into shoot

Treatments	Tillering 35 DAT	PI stage 60 DAT	Flowering (85 DAT)	Maturity (110 DAT)
S_0	79.1d	83.9c	87.1	86.7
S_{20}	82.3c	85.0b	88.2	88.1
S_{30}	83.5b	85.5b	88.1	89.2
S_{40}	84.1a	86.1a	88.0	90.2
Lsd $_{(0.05)}$	0.32	0.54	NS	NS
CV%				
Zn_0	77.9d	83.9c	86.4b	87.9
Zn_3	83.1b	85.5b	87.6ab	88.7
$Zn_{4.5}$	84.2a	86.6a	87.4ab	89.6
Zn_6	82.5c	85.5b	88.1a	89.2
Lsd$_{(0.05)}$	0.41	1.07	1.51	NS
CV%				
S x Zn	NS	NS	NS	NS

Within a column, values followed by the same letter (s) are not significantly different at 5% level of probability as per LSD test.

4.6. Flag leaf SPAD value

The value of SPAD is directly related to chlorophyll content in flag leaf, the value is increased with the increase of age of the plant and level of sulphur (Fig. 3). So, maximum value (37.48) of SPAD was recorded with 40 kg S ha^{-1} (S_3) at 85 DAT and the lowest value was recorded from the treatment with control (S_0) at 35 DAT. The chlorophyll content in leaf was increased with increased level of sulphur was also reported by Puteh *et al.* (2014).

SPAD value was also significantly influenced by zinc application; the maximum SPAD value (46.17) was obtained with 3 kg Zn ha^{-1} at anthesis (85 DAT) (Fig. 4). This might be due to application at anthesis increased the growth attributes which finally increased the SPAD value also increase. Similar type of result was also recorded by Alam *et al.*, (2015).

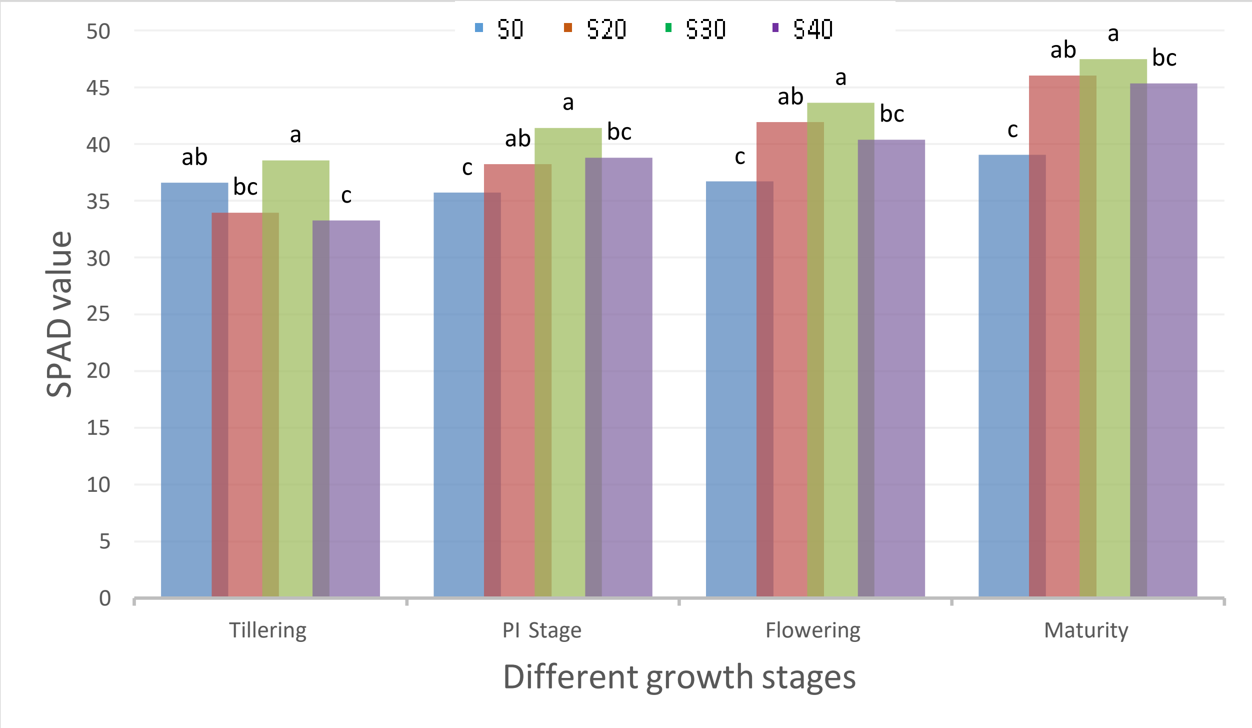

Fig. 3. Effect of different S levels on SPAD value of BRRI hybrid dhan2

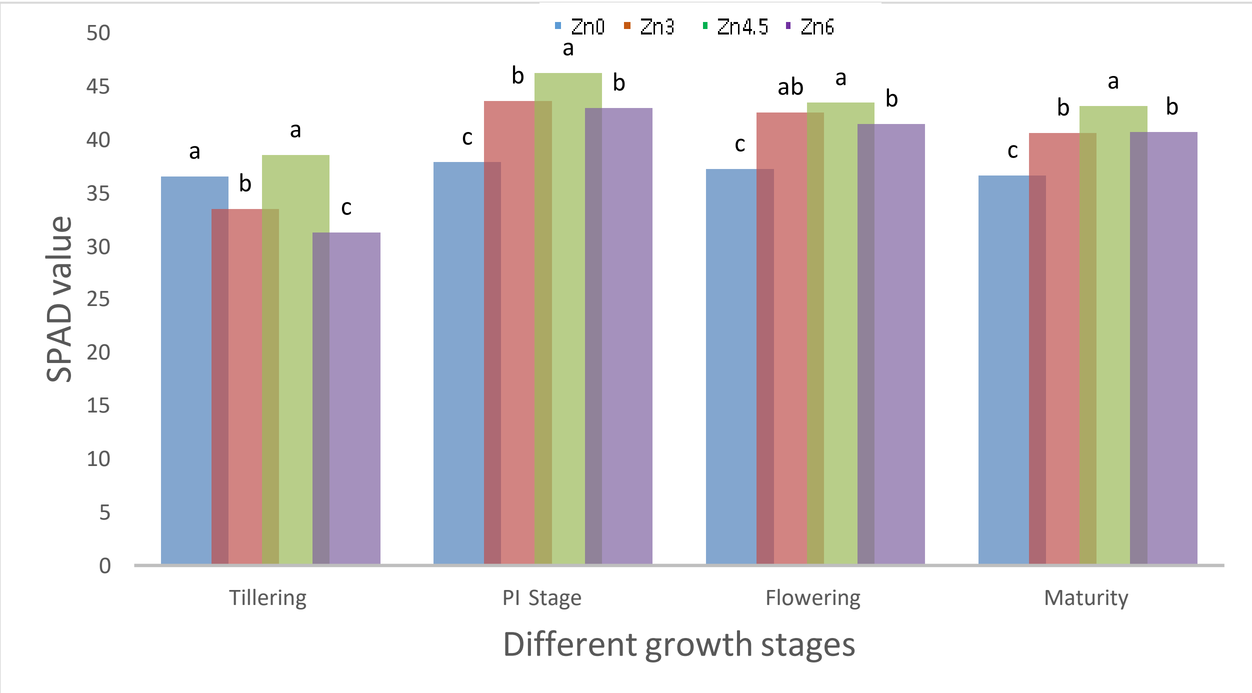

Fig. 4. Effect of different Zn levels on SPAD value of BRRI hybrid dhan2

4.7. Yield Components

4.7.1. Panicle hill^{-1}

Panicles hill^{-1} differed significantly due to different levels of S application (Table 5). The highest number of panicles hill^{-1} (9.32) was observed with S_{30} treatment that is when the crop was fertilized with 30 kg S ha^{-1} and the lowest (8.48) was obtained in control. It can be concluded from the above results that increase in S levels caused considerable increase in number of panicles hill^{-1}. The results corroborate the findings of Verma *et al.* (1991). Chowdhury *et al.* (1995) also reported that number of panicles of rice was increased due to S applications. Crop grown with Zn_3 treatment (3 kg Zn ha^{-1}) produced the highest panicles hill^{-1} (9.24) and the control treatment (Zn_0) produced the lowest panicles (8.43) hill^{-1} (Table 5). But the result is insignificant statistically. The interaction effective of sulphur and zinc was significant on the panicles hill^{-1}. Table 6 shows that the highest panicles hill^{-1} (10.50) was obtained by $S_3Zn_{4.5}$ treatment (30 kg S +4.5 kg Zn ha^{-1}) and the lowest figure was noticed at control treatment (S_0Zn_0).

4.7.2. Panicle length

Panicle length was significantly affected by different levels of sulphur applications (Table 5). The highest panicle length (23.45 cm) was found at 30 kg S ha^{-1} and the lowest (22.23) was at control.

Different levels of Zn produced a significant variation in panicle length. Table 5 shows that the highest panicle length (23.67cm) was observed with 6 kg Zn ha^{-1} and the lowest (22.47cm) was obtained in control treatment.0 kg Zn ha^{-1} and 4.5 kg Zn ha^{-1} produced statistically similar panicle length of rice.

The interaction effect of S and Zn levels showed significant influenced on the panicle length (Table 6). The highest panicle length (24.67 cm) was attained in $S_{4.5}Zn_6$ treatment (4.5 kg S +6 kg ha^{-1}). The lowest value (21.53 cm) was found from the control. Above findings focused that interaction of S and Zn has a pronounced influence on panicle length.

4.7.3. Filled grains panicle^{-1}

Table 7 shows that the highest number of filled grains panicle^{-1} (105.18) was observed with 30 kg S ha^{-1} and the lowest (83.58) was observed with 0 kg S ha^{-1}. Zinc brought about a significant variation in relation to number of filled grains panicle^{-1} (Table 5). It was noticed that the highest number of filled grains panicle^{-1} (104.42) was obtained by

4.5 kg Zn ha^{-1}.The control treatment (Zn_0) gave the lowest number of filled grains $panicle^{-1}$ (97.67).

There was significant variation in number of filled grains $panicle^{-1}$ due to S and Zn interaction (Table 6).The highest number of filled grains $panicle^{-1}$ (106.15) was achieved with 30 kg S ha^{-1} + 4.5 kg Zn ha^{-1} and the lowest (83.25) was with control treatment (S_0Zn_0).

4.7.4. Thousand grain weight

Data in the Table 5 shows that 1000-grain weight was significantly influenced by sulphur application. The highest 1000-grain weight (22.43 g) was found by 40 kg S ha^{-1} and the lowest (20.12g) was with 0 kg S ha^{-1}. Present results are in agreement with that of Islam (1978). 1000-grain weight was significantly influenced by Zn application (Table 5). The highest 1000-grain weight (22.01 g) was obtained by 6 kg Zn ha^{-1} and the lowest one (21.65 gm) at control treatment (Zn_0). The interaction effects of S and Zn was significant of 1000 grain weight .The highest 1000 grain weight (23.10 g) obtained at 40 kg S ha^{-1} + 6 kg Zn ha^{-1} and the lowest (20.40 g) was found at control treatment (Table 6).

Table 5. Effect of different Levels of S on yield and yield components of BRRI hybrid dhan2

Treatment	Panicles $hill^{-1}$	Panicle length (cm)	Filled grains $panicle^{-1}$	Weight of 1000-grains (g)
S_0	8.48d	22.23b	83.55c	20.12d
S_{20}	8.98b	22.40b	96.50b	20.92c
S_{30}	9.32a	23.45a	105.18a	21.73b
S_{40}	8.77c	22.25b	104.70a	22.43a
$Lsd_{(0.05)}$	0.20	0.73	7.91	0.56
***				
Zn_0	8.43	22.47c	97.67c	21.65b
Zn_3	8.86	22.75c	98.67bc	21.79b
$Zn_{4.5}$	9.24	23.25b	104.42a	21.77b
Zn_6	8.93	23.67a	101.08ab	22.10a
	NS	0.31	3.47	0.29
$Lsd_{(0.05)}$	4.57	4.80	4.05	5.23

Within a column, values followed by the same letter (s) are not significantly different at 5% level of probability as per LSD test.S_0 = 0 kg S ha^{-1}, S_1 =20kg S ha^{-1} , S_2= 30 kg S ha^{-1} , S_3 =40kg S ha^{-1} , Zn_0 = 0 kg Zn ha^{-1} , Zn_1= 3kg Zn ha^{-1} , Zn_2= 4.5kg Zn ha^{-1} , Zn_3 =6kg $Znha^{-1}$, NS=Non Significance , CV=Coefficient of variance

Table 6: Interaction effect of different levels of S and Zn on yield and yield components of BRRI hybrid dhan 2

Treatment	Panicle hill^{-1}	Panicle length (cm)	Filled grains panicle^{-1}	Weight of 1000-grains (g)
S_0Zn_0	7.96fg	21.53g	83.25	20.40
S_0Zn_3	8.76ef	22.16f	83.69	20.47
$S_0Zn_{4.5}$	8.43ef	22.50ef	84.55	20.50
S_0Zn_6	7.78g	22.53ef	83.52	20.63
$S_{20}Zn_0$	9.03bc	22.50ef	96.34	21.26
$S_{20}Zn_3$	9.10bc	22.67ef	96.45	21.56
$S_{20}Zn_{4.5}$	9.16bc	22.67ef	97.46	21.60
$S_{20}Zn_6$	9.46dc	23.16de	97.34	21.65
$S_{30}Zn_0$	8.93c	22.83ef	89.43	22.10
$S_{30}Zn_3$	9.43b	22.66ef	104.25	22.28
$S_{30}Zn_{4.5}$	10.06a	24.00bc	105.41	22.30
$S_{30}Zn_6$	8.70cd	22.33ab	106.15	22.68
$S_{40}Zn_0$	9.13bc	23.00de	104.75	22.79
$S_{40}Zn_3$	9.20bc	23.50cd	104.30	22.86
$S_{40}Zn_{4.5}$	9.40b	23.83bc	105.39	22.93
$S_{40}Zn_6$	9.6bc	24.67a	105.70	23.10
	**	*	NS	NS
CV (%)	4.64	4.52	4.92	4.03

Within a column, values followed by the same letter (s) are not significantly different at 5% level of probability as per LSD test. S_0 = 0 kg S ha^{-1}, S_{20} =20 kg S ha^{-1}, S_{30}= 30 kg S ha^{-1} , S_{40} =40 kg S ha^{-1}, Zn_0 = 0 kg Zn ha^{-1}, Zn_3=3 kg Zn ha^{-1}, $Zn_{4.5}$= 4.5 kg Zn ha^{-1}, Zn_6 =6 kg Znha^{-1} NS=Non Significance, CV= Coefficient of variance

4.8. Yield

4.8.1. Grain yield

Grain yield showed a significant variation for different sulphur levels (Table 7). Among the treatments S_2 (30 kg S ha^{-1}) produced significantly the highest grain yield (5.65 t ha^{-1}) and the lowest (4.07 t ha^{-1}) was found from the control .Higher grain yield at 30 kg S ha^{-1} might have resulted from the cumulative favourable effect of number of effective tillers hill^{-1} and filled grain panicle^{-1}. The result obtained is in conformity with the findings of Adhikari *et al.*, (2018). Grain yield was influenced significantly due to Zn application.

The highest grain yield (5.40 t ha^{-1}) was observed at $Zn_{4.5}$ treatment (4.5 kg Zn ha^{-1}) and the lowest yield (5.08 t ha^{-1}) was recorded in control treatment (Table 7). The interaction effect of S and Zn significantly influenced grain yield (Table 8). The highest grain yield (6.13 t ha^{-1}) was recorded in $S_{30}Zn_{4.5}$ treatment (30 kg S ha^{-1} + 10 kg Zn ha $^{-1}$) and the lowest (3.96 t ha^{-1}) was found from control. It was clear from above result that S in conjunction with Zn produced higher grain yield. Similar opinion was put forward by Alam *et al.*, (2015) and Ahmed *et al.*, (1991) who reported that S in combination of Zn produced higher seed yield.

4.8.2. Straw yield

Different levels of S influenced on straw yield and the same trend was also found in case of the grain yield (Table 9). The production of higher straw yield (9.56 t ha $^{-1}$) in 30 kg S ha^{-1} might be due to the fact that S contributed primarily to encourage vegetative growth. The findings for these characters agree with the result obtained by Hoque and Khan (1981). Similar results were also found by Sharma and Singh (1997). Table 7 shows that straw yield was significantly influenced by Zn application .The highest straw yield (9.01 t ha^{-1}) was observed at 4.5 kg Zn ha^{-1} and the lowest straw yield (8.44 t ha^{-1}) was observed at control treatment (Zn_0). The interaction effect of S and Zn in relation to straw yield was found to be the as same as the trend as obtained in case of grain yield (Table 8). From this discussion , it is clear that 30 kg S ha^{-1} + 4.5 kg Zn ha $^{-1}$ had the best performance (9.53 t ha $^{-1}$) for straw yield .

4.8.3. Biological yield

Biological yield showed a significant variation for different S levels (Table 7). Among the treatment 30 kg S ha^{-1} produced the highest biological yield (15.07 t ha^{-1}) and the lowest (12.10 t ha^{-1}) was found from the control. Higher biological yield at 30 kg S ha^{-1} might have resulted from the cumulative favourable effect of number of effective tillers hill $^{-1}$, filled grains $panicle^{-1}$. The result obtained in this regard is at par with the findings of Chowdhury *et al*. (1995), Mandal and Halder, (1998). Biological yield was also influenced significantly due to Zn application (Table 7). The highest biological yield (14.76 t ha^{-1}) was observed at Zn_6 treatment (6 kg Zn ha^{-1}) and the lowest (12.48 t ha^{-1}) was recorded in control treatment. Table 8 shows that the interaction of S and Zn was also significant in regards to biological yield. The highest biological yield (15.68 t ha^{-1})

was recorded in 30 kg S ha^{-1} + 4.5 kg Zn ha $^{-1}$ and lowest (11.63 t ha^{-1}) was found from control.

4.9. Harvest index

Harvest index was not significantly influenced by S applications. The lowest harvest index (36.02 %) was observed 20 kg S ha^{-1} and the highest (38.59 %) was observed with 40 kg S ha^{-1}. Zinc had no significant effect in relation to harvest index (Table 7). It was noticed that the lowest harvest index (36.95 %) was obtained by 3 kg Zn ha^{-1} and the highest value (37.38 %) was obtained by control treatment (Zn_0). Statistically insignificant variation was observed in terms of harvest index due to combined effect of S and Zn application (Table 10). The highest harvest index (41.12 %) was recorded from the treatment combination, $S_{40}Zn_{4.5}$ whereas the lowest harvest index (33.30%) was observed from the treatment combination, S_0Zn_3.

Table 7. Effect of different Levels of S on yield and yield components of BRRI hybrid dhan 2

Treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	HI (%)
S_0	4.07c	7.65c	12.10c	36.88
S_{20}	4.87b	8.65b	13.45b	36.02
S_{30}	5.37a	9.56a	15.07a	35.96
S_{40}	5.65a	8.99ab	14.80a	38.59
$Lsd_{(0.05)}$				
Zn_0	5.08c	8.44c	12.48b	37.38
Zn_3	5.25ab	8.87ab	13.97ab	36.95
$Zn_{4.5}$	5.40a	9.01a	14.32ab	37.25
Zn_6	5.14bc	8.57bc	14.76a	37.21
LSD				NS
CV (%)	5.49	4.26	4.16	7.54

Within a column, values followed by the same letter (s) are not significantly different at 5% level of probability as per LSD test. S_0 = 0 kg S ha^{-1}, S_{20} =20 kg S ha^{-1}, S_{30}= 30 kg S ha^{-1}, S_{40} =40 kg S ha^{-1}, Zn_0 = 0 kg Zn ha^{-1}, Zn_3=3 kg Zn ha^{-1}, $Zn_{4.5}$= 4.5 kg Zn ha^{-1}, Zn_6 =6 kg Znha^{-1} NS=Non Significance, CV= Coefficient of variance

Table 8: Interaction effect of different levels of S and Zn on yield and yield components of BRRI hybrid dhan2

Treatment	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	HI (%)
S_0Zn_0	3.95f	7.70	11.63f	33.96
S_0Zn_3	4.06f	8.13	12.19ef	33.30
$S_0Zn_{4.5}$	4.13f	8.23	12.36ef	33.65
S_0Zn_6	4.10f	7.83	12.26ef	34.61
$S_{20}Zn_0$	4.93e	8.49	13.06e	33.99
$S_{20}Zn_3$	5.03e	9.10	14.13cd	35.18
$S_{20}Zn_{4.5}$	5.10de	9.16	14.26bc	56.92
$S_{20}Zn_6$	4.83e	8.13	12.36ef	33.87
$S_{30}Zn_0$	5.66bc	9.06	14.72ab	36.64
$S_{30}Zn_3$	5.76abc	9.16	14.92ab	38.87
$S_{30}Zn_{4.5}$	6.13a	9.53	15.68a	39.14
$S_{30}Zn_6$	5.86ab	9.13	14.99ab	39.97
$S_{40}Zn_0$	5.77abc	9.06	14.83ab	40.10
$S_{40}Zn_3$	5.40cd	9.10	15.09ab	39.99
$S_{40}Zn_{4.5}$	6.06ab	9.13	15.19ab	41.12
$S_{40}Zn_6$	5.96ab	8.70	14.10d	37.98
	*	NS	*	NS
CV (%)	4.28	4.19	5.57	42.93

Within a column, values followed by the same letter (s) are not significantly different at 5% level of probability as per LSD test. S_0 = 0 kg S ha^{-1}, S_{20} =20 kg S ha^{-1}, S_{30}= 30 kg S ha^{-1}, S_{40} =40 kg S ha^{-1}, Zn_0 = 0 kg Zn ha^{-1}, Zn_3=3 kg Zn ha^{-1}, $Zn_{4.5}$= 4.5 kg Zn ha^{-1}, Zn_6 =6 kg Znha^{-1} NS=Non Significance, CV= Coefficient of variance

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the Experimental Field of Sher-e-Bangla Agricultural University, Dhaka from November 2019 to May 2020 to study the effect of Zn and S on tillering, dry matter accumulation, leaf characteristics and yield performance of BRRI hybrid dhan2. The experiment comprised of two factor *viz.* (1) Factor A: Levels of S - i. S_0: 0 kg S ha^{-1}(control), ii. S_1: 20 kg S ha^{-1}, iii. S_2: 30 kg S ha^{-1}, iv. S_3: 40 kg S ha^{-1} and (2) Factor B: Levels of Zn- i. Zn_0: 0 kg Zn ha^{-1}(control), ii. Zn_1: 3.0 kg Zn ha^{-1}, iii. Zn_2: 4.5 kg Zn ha^{-1}, iv. Zn_3: 6.0 kg Zn ha^{-1}. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. There were 48 plots of size 2.5 m × 4.0 m in 3 blocks. The treatments of the experiment were assigned at random into each replication according to the experimental design. Seedlings were sown in seed bed and age of transplanted seedling was 35 days.

Data was collected on plant height, leaves $hill^{-1}$, leaf area index, chlorophyll content, tillers $hill^{-1}$, dry matter $hill^{-1}$, shoot dry matter accumulation, filled grains $panicle^{-1}$, unfilled grains $panicle^{-1}$, 1000 grain weight, grain yield and biological yield and harvest index. Significant variation was recorded for data on growth, yield and yield contributing parameters of experimental materials.

At maturity, plots treated with sulphur at 40 kg ha^{-1} produced the tallest plant (97.3 cm). Similar type of response was also noticed in case of zinc application. Application of Zn at 4.5 kg ha^{-1} recorded significantly higher plant height over no application of Zn; however it produces at par with Zn applied at 6 kg ha^{-1} (Zn_4 treatment) during entire life cycle. Maximum plant height (101.7cm) at maturity was recorded with application of 6 kg ha^{-1} (Zn_6 treatment), whereas corresponding minimum plant height (78.5 cm) was recorded with no application of Zn. As the sulphur levels was increased from 0 kg S ha^{-1} to 40 kg S ha^{-1}, the number of tillers increased significantly and recorded maximumat 60 DAT and thereafter it subsequently decline. However, at 35 DAS sulphur level failed to brings significant variations in number of tillers. The highest tillers per running meter at 60 DAS might be due to higher availability of nutrient which facilitated proper synchronized tillering. The maximum number of tillers (77.33 running m^{-1}) was obtained with 150 kg S *ha^{-1}* (S_3). The number of tillers per running meter was significantly influence by zinc application. Number of tillers at 35 and 85 DAT was recorded non-significant. The maximum tillers (72.33) were observed with 3 kg ha^{-1} zinc (Zn_3 treatment). Application of sulphur at 40 kg ha^{-1} produced highest LAI (4.17) at anthesis. Plots received 20 kg sulphur produced significantly higher LAI over no application and produced at par with other tested levels of sulphur in most of the stages. In case of zinc application highest LAI (4.29) was obtained with zinc at 6 kg ha^{-1} and minimum (3.89) with no application of sulphur (S_0) at anthesis. However lower LAI was notice during 35 days after transplanting. The treatment ($Zn_{4.5}$) consisting of zinc at kg ha^{-1} produced significantly higher LAI (4.13) over no application of zinc and at 3 kg ha^{-1} (Zn_3 treatment), however it produced at par with zinc applied at 6 kg ha^{-1}. At maturity the range of dry matter accumulation was limited and it was recorded minimum (25.71 g $hill^{-1}$) to maximum (27.65 g $hill^{-1}$). The highest (28.25 g $hill^{-1}$) and the lowest (7.28 g $hill^{-1}$) dry matter was accumulated in case of Zn_6 (6 kg) and Zn_0 (0 kg) treatments at maturity and tillering. The dry matter share of root was maximum at tillering (35 DAT) and it was more than 15% across the levels of sulphur and zinc except at S_0 (0 kg) treatment where it was 20.9%. Gradually diversion of photosynthetic was more towards shoot and maximum at the time of maturity. Sulphur prove crucial when it matter most, maximum (90.2%) was recorded with 40 kg S application, moreover, minimum (86.7%) was noticed in case of plot treated with 0 kg sulphur. Zinc treatments had the little effect on dry matter translocation (%) into the shoot at anthesis and maturity. So, maximum value (37.48) of SPAD was recorded with 40 kg S ha^{-1} (S_3) at 85 DAT and lowest value was recorded with control (S_0) at 3T DAT. SPAD value was also significantly influenced by zinc application; the maximum SPAD (46.17) was obtained with 3 kg S ha^{-1} at anthesis (85 DAT). The highest number of panicles $hill^{-1}$ (9.32) was observed with S_{30} treatment that is when the crop was fertilized with 30 kg S ha^{-1} and the lowest (8.48) was obtained in control. Crop grown with Zn_3 treatment (3 kg Zn ha^{-1}) produced the highest panicles $hill^{-1}$ (9.24) and the control treatment (Zn_0) produced the lowest panicles (8.43) $hill^{-1}$ (Table 7). The highest panicles $hill^{-1}$ (10.50) was obtained by $S_{30}Zn_{4.5}$ treatment (30 kg S +4.5 kg Zn ha^{-1}) and the lowest figure was noticed at control treatment (S_0Zn_0). The highest panicle length (23.45 cm) was found at 30 kg S ha^{-1} and the lowest (22.23) was at control. Different levels of Zn produced a significant variation in panicle length. The highest panicle length (23.67cm) was observed with 6 kg Zn ha^{-1} and the lowest

(22.47cm) was obtained in control treatment.0 kg Zn ha^{-1} and 4.5 kg Zn ha^{-1} produced statistically similar panicle length of rice. The highest panicle length (24.67 cm) was attained in $S_{-4.5}$ Zn_6 treatment (4.5 kg S + 6 kg ha^{-1}). The lowest value (21.53 cm) was found from the control. The highest number of filled grains $panicle^{-1}$ (105.18) was observed with 30 kg Sha^{-1} and the lowest (83.58) was observed with 0 kg S ha^{-1}. The highest number of filled grains $panicle^{-1}$ (104.42) was obtained by 4.5 kg Zn ha^{-1}. The control treatment (Zn_0) gave the lowest number of filled grains $panicle^{-1}$ (97.67). The highest number of filled grains $panicle^{-1}$ (106.15) was achieved with 30 kg S ha^{-1} + 4.5 kg Zn ha^{-1} and the lowest (83.25) was with control treatment (S_0Zn_0). The highest 1000-grain weight (22.43 g) was found by 40 kg S ha^{-1} and the lowest (20.12g) was with 0 kg S ha^{-1}. The highest 1000- grain weight (22.01 g) was obtained by 6 kg Zn ha^{-1} and the lowest one (21.65 g) at control treatment (Zn_0). The highest 1000 grain weight (23.10 g) obtained at 40 kg S ha^{-1} + 6 kg Zn ha^{-1} and the lowest (20.40 g) was found at control treatment.

Among the treatments S_2 (30 kg S ha^{-1}) produced significantly highest grain yield (5.65 t ha^{-1}) and the lowest (4.07 t ha^{-1}) was found from the control. The highest grain yield (5.40 t ha^{-1}) was observed at $Zn_{4.5}$ treatment (4.5 kg Zn ha^{-1}) and the lowest yield (5.08 t ha^{-1}) was recorded in control treatment. The highest grain yield (6.13 t ha^{-1}) was recorded in $S_{30}Zn_{4.5}$ treatment (30 kg S ha^{-1} + 4.5 kg Zn ha $^{-1}$) and the lowest (3.96 t ha^{-1}) was found from control. The production of higher straw yield (9.56 t ha $^{-1}$) in 30 kg S ha^{-1} might be due to the fact that S tends primarily to encourage vegetative growth. The highest straw yield (9.01 t ha^{-1}) was observed at 4.5 kg Zn ha^{-1} and the lowest straw yield (8.44 t ha^{-1}) was observed at control treatment (Zn_0). The interaction effect of S and Zn in relation to straw yield was found to be the same trend as obtained by grain yield. Among the treatment 30 kg S ha^{-1} produced the highest biological yield (15.07 t ha^{-1}) and the lowest (12.10 t ha^{-1}) was found from the control. The highest biological yield (14.76 t ha^{-1}) was observed at Zn_6 treatment (6 kg Zn ha $^{-1}$) and the lowest (12.48 t ha^{-1}) was recorded in control treatment. The interaction of S and Zn was also significant in regards to biological yield. The highest biological yield (15.68 t ha^{-1}) was recorded in 30 kg S ha^{-1} + 4.5 kg Zn ha $^{-1}$ and lowest (11.63 t ha^{-1}) was found from control. The lowest harvest index (36.02 %) was observed 20 kg S ha^{-1} and the highest (38.59 %) was observed with 40 kg S ha^{-1}. The highest harvest index (41.12 %) was recorded from the treatment combination, $S_{40}Zn_{4.5}$ whereas the lowest harvest index (33.30%) was observed from the treatment combination, S_0Zn_3. .

Conclusion

1. Number of tillers per running meter (*ca*. 74.13 and 67.84) and leaf area index (*ca*. 3.56 and 3.64) and dry matter translocation (%) into shoot (*ca*. 89.7 and 89.4) were significantly higher with high doses of sulphur and zinc: 30 kg S ha^{-1} to 40 kg S ha^{-1} and 4.5 kg Zn ha^{-1} to 6.0 kg Zn ha^{-1}.
2. Among the treatment combinations, $S_{30}Zn_{4.5}$ (30 kg S ha^{-1} + 4.5 kg Zn ha^{-1}) gave the highest grain yield (6.13 t ha^{-1}) attributed with higher panicles $hill^{-1}$ (10.50), filled grains $panicle^{-1}$ (106.15) and 1000-grain weight (23.10 g)

Recommendation

- Combined application of 30 kg S ha^{-1} and 4.5 kg Zn ha^{-1} are suitable for getting higher yield from BRRI hybrid dhan2 in *Boro* season.
- However, it needs more trials under farmer's field conditions at different agro-ecological zones of Bangladesh for the conformation of the results.

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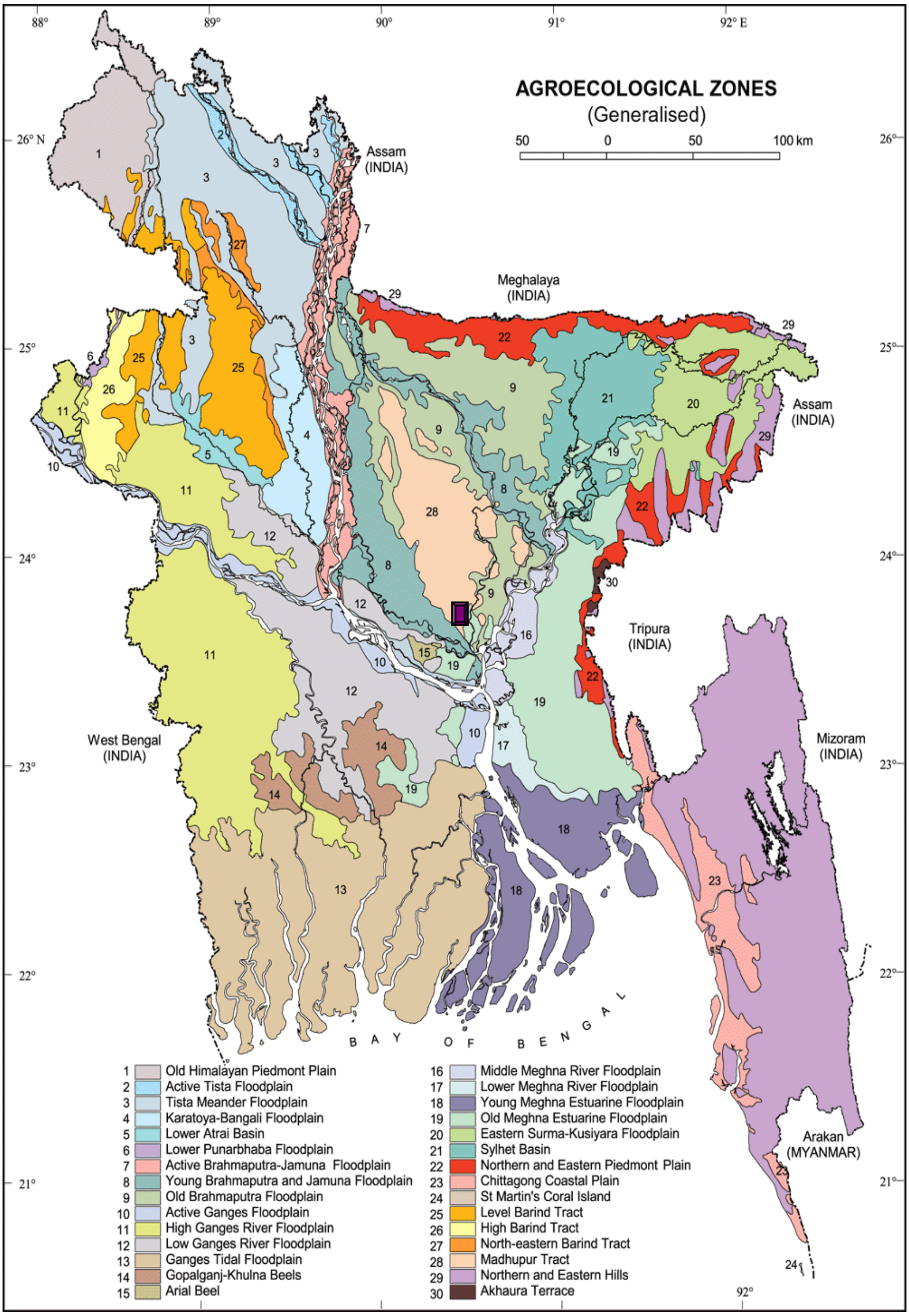
APPENDICES

Appendix I. The Map of the experimental site



Appendix II. Monthly record of air temperature, relative humidity, rainfall, and sunshine (average) of the experimental site during the period from November, 2019 to May, 2020

Month	Air temperature (^0c)			Relative humidity (%)	Rainfall (mm)	Sunshine (hr)
	Max.	Mini.	Mean			
November’19	32	24	29	65	42.8	349
December’19	27	19	24	53	1.4	372
January’20	27	18	23	50	3.9	364
February’20	30	19	26	38	3.1	340
March’20	35	24	31	38	19.6	353
April’20	38	25	33	54	292.4	315
May’20	37	27	33	59	152.5	297

Source: Bangladesh Meteorological Department (Climate & weather division) Agargoan, Dhaka–1207

Appendix III. Soil characteristics of experimental field as 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

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	26
% Silt	43
% clay	31
Textural class	Sandy loam
pH	5.9
Cation exchange capacity	2.64 meq 100 g/soil
Organic matter (%)	1.15
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

EFFECT OF ZINC AND SULPHUR ON GROWTH AND YIELD OF BRRI HYBRID DHAN2 (*Oryza sativa L.*)

BY

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A Thesis
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CERTIFICATE

*This is to certify that the thesis entitled '***EFFECT OF ZINC AND SULPHUR ON GROWTH AND YIELD OF BRRI HYBRID DHAN2 (*Oryza sativa L.*)***' submitted to the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE INAGRICULTURAL BOTANY****, embodies the results of a piece of bona-fide research work carried out by* ***MD. OWAHEDUNNABY****, Registration No.***19-10100*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

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

Dated: June, 2021
Dhaka, Bangladesh

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DEDICATED

TO

MY BELOVED PARENTS

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The Author

EFFECT OF ZINC AND SULPHUR ON GROWTH AND YIELD OF BRRI HYBRID DHAN2 (*Oryza sativa L.*)

MD. OWAHEDUNNABY

ABSTRACT

The experiment was conducted in the Research Farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka during November, 2019 to June, 2020 to ascertain the role of zinc and sulphur on growth and yield of BRRI hybrid dhan2 (*Oryza sativa L.*). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Four levels of both nutrients i.e. sulphur and zinc, total 16 treatments were tested in this experiment. Data on different morpho-physiological traits and yield were recorded and marked differences were observed in case of individual treatments and in most of the cases combined effect were insignificant. However, the tallest plant (97.3 cm and 101.7cm) at maturity and maximum tillers per running meter (119.58 and 109.75) were recorded at 60 days after transplanting (DAT) with application of 40 kg S and 6 kg Zn dependently. With the advance of stage, dry matter accumulation was increased irrespective of both nutrients treatment, it was not like the leaf area index (LAI) which was decreased after panicle initiation stage. The highest LAI (4.17 and 4.29) at anthesis was produced in the plots treated with 40 kg ha^{-1} S and Zn at 6 kg ha^{-1} singly. But at maturity maximum LAI were achieved from30 kgha^{-1} S and Zn at 4.5 kg ha^{-1} discretely. Maximum grain yield (6.13 t ha^{-1}) was achieved with combined application of 30kg sulphur and 4.5 kg zinc, whereas corresponding minimum rice yield (3.95 tha^{-1}) was recorded with absolute control plots where no application of zinc and sulphur was done during entire experimentation period. In short, BRRI hybrid dhan2 produced the highest number of tillers, the highest number of filled grains panicle^{-1}. The longest panicle and the highest weight of 1000 grains, and consequently provided the highest grain yield.

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LIST OF ABBREVIATIONS

%	Percent
AEZ	Agro-Ecological Zone
BBS	Bangladesh Bureau of Statistics
BRRI	Bangladesh Rice Research Institute
PI	Panicle Initiation
PE	Panicle Emergence
Cont’d	Continued
CV%	Percentage of Coefficient of Variance
DAF	Days after flowering
DAT	Days after transplanting
DF	Degree of freedom
DM	Dry matter
et al.	and others
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate
GDP	Gross Domestic Product
IRRI	International Rice Research Institute
Kg	Kilogram
LAI	Leaf area index
LSD	Least significant difference
m^2	Square meter
Mt/ha	Million ton per hectare
MV	Modern varieties
$t\ ha^{-1}$	Ton per hectare
UNDP	United Nations Development Program
USDA	United States Department of Agriculture
viz.	Namely