INFLUENCE OF SULPHUR AND ZINC ON THE YIELD OF T. AMAN RICE (BRRI dhan34)

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MY BELOVED PARENTS

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CERTIFICATE

This is to certify that the thesis entitled **'Influence of Sulphur and Zinc on the Yield of T. Aman Rice (BRRI dhan34)'** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **Master of Science** in **Soil Science**, embodies the result of a piece of bonafide research work carried out by **Mashuka Sharmin**, Registration number: **06-02074** 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 duly been acknowledged.

Dated:
Dhaka, Bangladesh

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ABSTRACT

The experiment was conducted in the Farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from June to November 2013 to find out the influence of sulphur and zinc on yield of transplanted (T.) aman rice. BRRI dhan34 was used as the test crop in this experiment. The experiment consisted of two factors. Factor A: 3 levels of sulphur (S_0: 0 kg S ha^{-1}, S_1: 8.0 kg S ha^{-1}, S_2: 12.0 kg S ha^{-1}) and Factor B: 4 levels of zinc (Zn_0: 0 kg Zn ha^{-1}, Zn_1: 1.0 kg Zn ha^{-1}, Zn_2: 2.0 kg Zn ha^{-1}, Zn_3: 3.0 kg Zn ha^{-1}). The experiment was laid out in a randomized complete block design (RCBD) with three replications. In case of sulphur fertilizer, the highest yield and yield contributing characters were observed from S_2, whereas the lowest was recorded from S_0. For different levels of zinc, the highest yield and yield contributing characters were observed were recorded from Zn_3, whereas the lowest was recorded from from Zn_0. Due to the interaction effect of different levels of sulphur and zinc, at 30, 45, 60, 75 DAT and harvest, the tallest plant (26.65, 54.48, 87.32, 98.67 and 122.53 cm, respectively), the maximum number of total tillers hill^{-1} (20.60), the longest panicle (29.65 cm), the highest grain yield (4.00 t ha^{-1}), the highest straw yield (5.36 t ha^{-1}) and the maximum uptake by grain for N (38.45 kg ha^{-1}), P (15.93 kg ha^{-1}), K (19.79 kg ha^{-1}), S (6.36 kg ha^{-1}) and Zn (0.819 kg ha^{-1}) were recorded from S_2Zn_3, whereas the shortest plant (16.89, 45.09, 63.66, 81.05 and 103.81 cm, respectively), the minimum number of total tillers hill^{-1} (13.13), the shortest panicle (20.23 cm), the lowest grain yield (2.13 t ha^{-1}), lowest (3.88 t ha^{-1}) and the minimum uptake by grain for N (12.55 kg ha^{-1}), P (6.08 kg ha^{-1}), K (9.85 kg ha^{-1}), S (3.48 kg ha^{-1}) and Zn (0.287 kg ha^{-1}) was recorded from S_0Zn_0. Therefore, a package of 8.0 kg S ha^{-1} along with 2.0 kg Zn ha^{-1} may be recommended for T. aman cultivation in Shallow Red Brown Terrace Soil under Madhupur Tract (AEZ-28) of Dhaka district.

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CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important food and widely grown crop in tropical and subtropical regions (Singh *et al*., 2012). It is the staple food of not only Bangladesh but also for South Asia (Hien *et al.*, 2006) and it provides 21% and 15% per capita of dietary energy and protein, respectively (Maclean *et al*., 2002). It is the staple food of more than three billion people in the world, most of who live in Asia (IRRI, 2009). Rice production and consumption is concentrated in Asia, where more than 90% of all rice is consumed (FAO, 2006). In Bangladesh, the geographical, climatic and edaphic conditions are favorable for year round rice cultivation. The slogan 'Rice is life' is most appropriate for Bangladesh as this crop plays a vital role in our food security and is a means of livelihood for millions of rural peoples. However, the national average rice yield in Bangladesh (4.2 t ha^{-1}) is very low compared to other rice growing countries, like China (6.30 t ha^{-1}), Japan (6.60 t ha^{-1}) and Korea (6.30 t ha^{-1}) (FAO, 2009).

Agriculture in Bangladesh is dominated by intensive rice cultivation covering 80% of arable land. The population of Bangladesh is increasing at an alarming rate and the cultivable land is reducing due to urbanization and industrialization resulting in more shortage of food. As it is not possible to have horizontal expansion of rice area so, rice yield $unit^{-1}$ area should be increased to meet this ever-increasing demand of food. Rice and rice based cropping system have important role in the Eastern Indo Gangetic Plain to increase food production for a rapidly growing population. Rice yields are mothly stagnating during the last decade mainly due to imbalance in fertilizer use, soil degradation, type of cropping system practiced, lack of suitable rice genotypes/varieties for low moisture adaptability and disease resistance (Prakash, 2010).

Among the production factors affecting crop yield, essential nutrient is the single most important factor that plays a dominant role in yield increase if other production factors are not limiting. It is reported that chemical fertilizers today hold the key to success of production systems of Bangladesh agriculture being responsible for about 50% of the total crop production (BARC, 1997). Nutrient imbalance can be minimized by judicious application of different fertilizers. In Bangladesh, there is tendency to use indiscriminate amount of nitrogenous fertilizers and very limited amount of other nutrients' containing high analysis chemical fertilizers (Rahman *et al*., 2008). Intensive crop cultivation using high yielding varieties with imbalanced fertilization has lead to mining out the inherent plant nutrients and thereby fertility status of soils severely declined with an increase in the incidence of the deficiencies of plant nutrients, including sulphur and zinc for the rice soils. On an average to produce one ton of rice grain of high-yielding varieties is removed about 22 kg N, 7 kg P_2O_5, 32 kg K_2O, 5 kg MgO, 4 kg CaO, 1 kg S and 40 g Zn from the soil (Chaudhary *et al*., 2007).

Sulphur (S) is one of the sixteen essential plant nutrients and ranks fourth major nutrient next to N, P and K. Among the essential elements, sulphur is very much beneficial for increasing the production of rice and is one of the major essential nutrient elements involved in the synthesis of chlorophyll, certain amino acids like methionine, cystine, cysteine and some plant hormones such as thiamine and biotin (Rahman *et al*., 2007). Sulphur, however, is taken up by the roots of most plants in the oxidized sulphate form. Accumulation of sulphur in the plant tissue affected floral initiation and anthesis of rice (Tiwari, 1994). Growing of sulphur responsive crops, high intensive cropping and use of sulphur free fertilizers caused S deficiency in soils (Tandon and Tiwari, 2007). Sulphur requirement of rice varies according to the nitrogen supply. Sulphur is required early in the growth of rice plants. If it is limited during early growth, then tiller number and therefore final yield might 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 is a major component and activator of several enzymes involved in metabolic activities (Klug and Rhodes, 1987). Zinc 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 (Chaudhary *et al*., 2007; Muthukumararaja and Sriramachandrasekharan, 2012). Zinc deficiency is prevalent worldwide in temperate and tropical climates (Fageria *et al*., 2003; Slaton *et al*., 2005). Zinc deficiency and response of rice to zinc under flooded condition have been studied by many workers (Gangwar *et al*., 1989; Kausar *et al*., 2004; Naik and Das, 2007; Mollah *et al*., 2009; Fageria *et al*., 2011).

Bangladeshi farmers are widely used N, P and K fertilizers but not S and Zn fertilizer. A marked higher incidence of micronutrient deficiency is found in crop due to intensive crop cultivation, loss of fertile top soil and losses of nutrient (Rahman *et al*., 2008; Somani, 2008 and Singh *et al*., 2011). There is a need to ascertain and promote the use fertilizers required to correct the deficiency of all these nutrients especially sulphur and zinc. Understanding the importance of rice and the role of sulphur and zinc for its growth, development maturation and yield, the present research work has been undertaken with the following objectives:

- To study the response of rice to S and zn application;
- To find out the optimum dose of S and Zn for maximizing the yield of rice.

CHAPTER II

REVIEW OF LITERATURE

Sulphur and zinc play crucial role for yield and yield attributes of rice. The available literatures that are related to the effect of sulphur and zinc application on the yield and yield attributes of rice are reviewed below under the following headings-

2.1 Effect of sulphur on rice yield attributes and yield

The productivity of wheat–rice cropping system is declining over time despite adequate supply of major nutrients is reported by Singh and Singh (2014). It may be due to deficiency of nutrients like sulphur. A field experiment was conducted with treatments consisting of three levels of sulphate-sulphur (0, 15, 30 and 45 kg ha^{-1}) to study the sulphur balance and productivity in wheat-rice cropping sequence in a sandy clay loam soil. The agronomic efficiency and apparent sulphur recovery decreased with increase in levels of sulphate but the percent response increased with increasing sulphate application. Application of sulphur showed the positive sulphur balance, while it was negative for control.

Dixit *et al*. (2012) carried out a field experiment to study the effect of sulphur and zinc on yield, quality and nutrient uptake by hybrid rice grown in sodic soil and found that application of 40 kg S ha^{-1} recorded significantly high grain and straw yield, protein content and sulphur uptake.

A field experiment was conducted by Jawahar and Vaiyapuri (2011) at Experimental Farm, Annamalai University, Annamalai Nagar, Tamil Nadu, India to study the effect of sulphur and silicon fertilization on yield and nutrient uptake. The treatments comprised four levels of sulphur (0, 15, 30 and 45 kg ha^{-1}). They observed highest yield and nutrient uptake of rice due to application 45 kg S ha^{-1}.

An experiment was conducted by Rahman *et al*. (2009) to know the effect of different levels of sulphur on growth and yield of BRRI dhan41 at Soil Science laboratory field of Bangladesh Agricultural University, Mymensingh during T. Aman season. There were eight treatments and they were T_0 (without S), T_1 (50% RFD of S), T_2 (75% RFD 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 increased due to different levels of S application.

Mrinal and Sharma (2008) conducted a field trials during the rainy (kharif) season to study the relative efficiency of different sources (gypsum, elemental sulphur and cosavet) and varying levels of sulphur (0, 10, 20, 30 and 40 kg S ha^{-1}) in rice. The growth and yield attributing characters of rice increased with the sulphur application. The grain and straw yields of rice increased significantly with increasing levels of sulphur up to 30 kg S ha^{-1}. The difference between sulphur sources was generally not significant.

Alamdari *et al*. (2007) conducted a field experiments to study the effect of sulphur (S) and sulfate fertilizers on zinc (Zn) and copper (Cu) by rice and reported that both Zn and Cu contents in the grain increased when N, P, K, S and Zn, Cu and Mn sulfate were applied together.

Bhuvaneswari *et al*. (2007) conducted a field experiment during kharif season, to study the effect of sulphur (S) at varying rates, i.e. 0, 20, 40 and 60 kg ha^{-1}, with different organics, each applied at 12.5 t ha^{-1}, on yield, S use efficiency and S optimization of rice cv. ADT 43. The results revealed that rice responded significantly to the application of S and organics compared to the control. The highest grain (5065 kg ha^{-1}) and straw yields (7524 kg ha^{-1}) was obtained with 40 kg S ha^{-1}.

Oo *et al*. (2007) conducted a field experiment during the rainy season at the research farm of the Indian Agricultural Research Institute, New Delhi to study the effect of N and S levels on the productivity and nutrient uptake of aromatic rice and concluded that aromatic rice requires 20 kg S ha^{-1} for increased productivity and uptake of N, P, K and S under transplanted puddled conditions.

Basumatary and Talukdar (2007) conducted a field experiment at the University, Jorhat, Assam, India to find out the direct effect of sulphur alone and in combination with graded doses of farmyard manure on rapeseed and its residual effects on rice with respect to yield, uptake and protein content. The N:S ratio in both crops progressively decreased with increasing sulphur levels up to 45 kg ha^{-1}. The lowest N:S ratio was observed upon treatment with 45 kg S ha^{-1} alone with 3.0 tonnes farmyard manure per hectare.

Islam *et al*. (2006) to evaluated the effect of gypsum (100 kg ha^{-1}) applied before planting, and at 30 and 60 days after planting, on the nutrient content of transplanted Aus rice (BR-2) in the presence of basal doses of N,P,K, fertilizers. Application of gypsum at different dates increased N, P, K, S, Ca and Mg contents progressively, whereas the Na content was found to decrease. The highest increase of N, P, K, S, Ca and Mg was obtained when the gypsum was applied at 30 days after planting. Synthesis of protein was accelerated with all the treatments of gypsum, and the content was much higher due to application of gypsum at 30 days after planting.

Huda *et al*. (2004) conducted an experiment at the Soil Science Department of Bangladesh Agricultural University, Mymensingh, Bangladesh to evaluate the suitable extractants for available sulphur and critical limits of sulphur for wetland rice soils. Twenty-two soils from 0-15 cm depth were collected from different locations under Old Brahmaputra Flood Plains of the country (AEZ 9). Both geographical and statistical methods were used to determine the critical levels of S. The critical limit for S was found to be 0.12% at 56 days of crop growth.

Biswas *et al*. (2004) reported the effect of S in different region of India. The optimum S 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%.

Chandel *et al*. (2003) conducted a field experiment to investigate the effect of sulphur nutrition on the growth and S content of rice and mustard grown in sequence with 4 S levels (0, 15, 30 and 45 kg ha^{-1}). They stated that increasing S levels in rice significantly improved yield attributes i.e. tiller number, leaf number, dry matter production and harvest index of rice up to 45 kg ha^{-1}.

Singh and Singh (2002) carried out a field experiment to see the effect of different nitrogen levels and S levels (0, 20 and 40 kg ha^{-1}) on rice cv. Swarna and PR-108 in Varanasi, Uttar Pradesh. India. They reported that plant height, tillers m^{-2} row length, dry matter production, panicle length and grains panicle $^{-1}$ were significant with increasing levels of S up to 40 kg S ha^{-1}. They also found that total N uptake, grain, straw and grain protein yields significantly improved with the increasing level S application being the maximum at 40 kg S ha^{-1} respectively.

Sen *et al*. (2002) carried out an extensive study on application of sulphur through single super phosphate in a sulphur deficient area of Murshidabad district, in India, in a rice-mustard cropping sequence. Significant yield increase in rice with application of sulphur at 30 kg ha^{-1} and its residual effect on mustard was observed. Sulphur application not only helped to increase yield in both crops but also helped to control the movement and distribution of different cationic micronutrients in both the crops.

Peng *et al*. (2002) carried out a field experiment where the average content of available S in these soil samples was 21.7 mg kg^{-1}. The soil with available S content was lower than the critical value of 16 mg kg^{-1} accounted for 57.8%. Field experiments showed that there was a different yield-increasing efficiency by applying S at the doses of 20-60 kg ha^{-1} to rice plant.

Nad *et al*. (2001) observed that ammonium sulfate and gypsum, as compared to pyrite or elemental sulphur, maintained adequate N to S ratio in rice, resulting in a reduction in the percent of unfilled grain, a major consideration in rice yield.

Babu *et al*. (2001) carried out field studies and stated that the direct effect of sulphur through single super phosphate on hybrid rice resulted in a significant increase of 21% in grain yield with an S use efficiency of 13 kg grain kg^{-1} at 45 kg S ha^{-1}.

Vaiyapuri and Sriramachandrasekharan (2001) conducted an experiment on integrated use of green manure with graded levels of sulphur (0, 20, and 40 kg ha^{-1}) applied through three different sources in rice cv. ADT 37. It appeared that the maximum nutrient uptake (115.5, 27.6, 220.2 and 24.8 kg ha^{-1} for N, P, K and S, respectively) with rice yield (5.07 t ha^{-1}) were noticed for the application of 40 kg sulphur ha^{-1}.

Raju and Reddy (2001) conducted field investigations to study the response of both hybrid and conventional rice to sulphur (20 kg ha^{-1}) and zinc applications and reported significant improvement in grain yield due to sulphur application.

2.2 Effect of zinc on rice yield attributes and yield

Kabeya and Shankar (2013) reported that rice (*Oryza sativa*) is the worlds' most important cereal and potentially an important source of zinc (Zn) for people who eat mainly rice. Zinc deficiency being a major constraint to reduce the potential yield of rice. To improve Zn delivery by rice, plant Zn uptake and internal allocation need to be better investigated. Field experiments were carried out to find out the effect of three different levels of zinc on rice zinc contrasting lines, high zinc groups and low zinc groups. The experiments revealed that increased Zn supply induced increased plant Zn uptake rate throughout the crop development in both high zinc groups and low zinc groups. The highest effect was observed when treated with 30 kg $ZnSO_4$ ha^{-1} irrespective of zinc groups. However, high zinc groups showed better uptake ability in zinc content and overall performance in growth characteristics.

The study was conducted Boonchuay *et al.* (2012) applied 8 foliar Zn treatments of 0.5% zinc sulfate ($ZnSO_4 \cdot 7H_2O$) to the rice plant at different growth stages. Foliar Zn increased paddy Zn concentration only when applied after flowering, with larger increases when applications were repeated. The largest increases of up to ten-fold were in the husk, and smaller increases in brown rice Zn. In the first few days of germination, seedlings from seeds with 42 to 67 mg Zn kg^{-1} had longer roots and coleoptiles than those from seeds with 18 mg Zn kg^{-1}, but this effect disappeared later. The benefit of high seed Zn in seedling growth is also indicated by a positive correlation between Zn concentration in germinating seeds and the combined roots and shoot dry weight. Zinc in rice grains can be effectively raised by foliar Zn application after flowering, with a potential benefit of this to rice eaters indicated by up to 55% increases of brown rice Zn, and agronomically in more rapid early growth and establishment.

A field experiment was conducted by Dixit *et al.* (2012) to study the effect of sulphur and zinc on yield, quality and nutrient uptake by hybrid rice grown in sodic soil and that positive response of hybrid rice to zinc application was noticed significantly up to the zinc dose @ 10 kg ha^{-1}.

An experiment was carried out by *et al.* (2012) at Sari, Mazandaran, Iran. This experiment was done as split plot in randomized complete blocks design based three replications. Zinc fertilizer application was chosen as main plots (0, 2 and 4 kg ha^{-1}) and genotypes as sub plots. The maximum panicle number m^{-2} and harvest index were observed with 4 kg Zn ha^{-1} and the least of those was obtained in control treatment. The highest zinc content in grain, zinc uptake in grain and straw, and nitrogen uptake in grain were observed with 4 kg Zn ha^{-1}, as the most zinc content in straw, nitrogen, potassium, phosphorus and sulphur content in grain and straw, and nitrogen uptake in straw were observed highest with application of 4 and 2 kg Zn ha^{-1}.

Muthukumararaja and Sriramachandrasekhara (2012) reported that zinc deficiency in flooded soil is impediment to obtain higher rice yield. Zinc deficiency is corrected by application of suitable zinc fertilizer. The results revealed that rice responded significantly to graded dose of zinc. The highest grain (37.53 g pot^{-1}) and straw yield (48.54 g pot^{-1}) was noticed at 5 mg Zn kg^{-1}, which was about 100% and 86% greater than control (no zinc) respectively. The highest zinc concentration and uptake in grain and straw and DTPA-Zn at all stages was noticed at 7.5 mg Zn kg^{-1}. The linear regression analysis showed grain zinc concentration and grain Zn uptake caused 89.64 and 89.01% variation in rice yield. Similarly, the linear regression analysis of DTPA-Zn caused 98.31, 96.34 and 93.12% variation in yield of rice at tillering, panicle initiation and harvesting stages, respectively. The agronomic, physiological and agrophysiological apparent recovery and utilization efficiencies was highest at lower level of zinc application and decreased with Zn doses.

The study was conducted by Mustafa *et al*. (2011) at agronomic research area, University of Agriculture, Faisalabad, 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. Maximum productive tillers per m^2 (249.80) were noted with basal application at the rate 25 kg ha^{-1} of $ZnSO_4$ (21% Zn) 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 paddy yield (5.21 t ha^{-1}) was achieved in treatment Zn_2 (Basal application at the rate of 25 kg ha^{-1} of $ZnSO_4.7H_2O$) and minimum paddy yield (4.17 t ha^{-1}) was noted in Zn_7 (foliar application at 75 DAT @ 0.5% Zn solution).

Naik and Das (2007) reported that rice is mostly transplanted under puddled low land soil conditions in India, where zinc (Zn) deficiency is a common problem. The objective of this study was to find out the efficacy of split application of Zn on growth and yield of rice in an inceptisol. The split application of Zn as $ZnSO_4.7H_2O$ performed better than its single basal application, while the split application of Zn-EDTA did not show any significant difference on yield and yield components of rice over its single basal application. Zn-EDTA was found to be better for growth and yield of rice among the two sources of Zn. The soil application of Zn at 1.0 kg ha^{-1} as Zn-EDTA (T_7) recorded highest grain yield of 5.42 t ha^{-1}, filled grain percentage of 90.2%, 1000-grain weight of 25.41 g and number of panicles m^{-2} of 452. The Zn content of grain and straw were also found to be maximum in the treatment T_7 i.e. 38.19 and 18.27 mg Zn kg^{-1}, respectively. Linear regression studies indicated that grain yield of rice is significantly influenced by Zn content of grain, Zn content of straw and DTPA extractable Zn content of soil at the level of 95.96, 96.74 and 95.57%, respectively.

A pot experiment was conducted by Khan *et al*. (2007) at Faculty of Agriculture Gomal University, Pakistan to evaluate the effect of different levels of zinc application on the yield and growth components of rice at eight different soil series. Zn as $ZnSO_4.7H_2O$ (21% Zn) was applied @ 0, 5, 10 and 15kg ha^{-1} along with the basal doses of 120 kg N, 90 kg P_2O_5 and 60 kg K_2O ha^{-1}. Thirty days old four seedlings of rice cv. IRRI-6 were grown. The increasing levels of Zn in these soil series significantly influenced yield and yield components of rice. Application of 10 kg Zn ha^{-1} appeared to be an optimum dose for rice crop in these soil series.

A study was carried out by Cheema *et al*. (2006) to evaluate the effect of four zinc levels on the growth and yield of coarse rice cv. IR-6 at Faisalabad, Pakistan. Four zinc levels viz., 2.5, 5.0, 7.5 and 10.kg $ZnSO_4$ ha^{-1} increased yield and yield component as compared with control. Plant height, number of tillers $hill^{-1}$, panicle bearing tillers, number of primary and secondary spikelets, panicle size, 1000 grain weight, paddy and straw yield and harvest index showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

A field experiment was conducted by Ullah *et al*. (2001) in Mymensingh, Bangladesh, to study the effect of zinc sulfate (0, 10, and 20 kg ha^{-1}) on rice cv. BR30. Zinc sulfate, along with 60 kg P_2O_5 and 40 kg K_2O ha^{-1}, was incorporated during land preparation. 80 kg N ha^{-1} was applied by 3 equal installments during land preparation, and at 25 and 60 days after transplanting. Plant height; tiller number; 1000-grain weight; grain and straw yields; and grain, straw, and soil Zn contents increased with zinc sulfate application. The tallest plants (75.667 cm) and the highest number of tillers (10.60 $hill^{-1}$), 1000-grain weight (28.700 g), and the concentration of Zn in straw (101.93 ppm) and grain (73.33 ppm) were obtained with 20 kg zinc sulfate ha^{-1}.

Raju and Reddy (2001) conducted field investigations to study the response of both hybrid and conventional rice to sulphur and zinc (10 kg ha^{-1}) applications and reported that zinc application failed to improve the yield markedly.

lBinod *et al*. (1998) conducted an experiment on rice (cv. Sita) with soil application of 0, 12.5 and 25 kg $ZnSO_4$ ha^{-1}. After transplanting, plants were fertilized with soil amount of 0, 12.5 and 25 kg $ZnSO_4$ ha^{-1} and they obtained best results with application of 25 kg $ZnSO_4$ ha^{-1}.

2.3 Combined effect of sulphur and zinc on rice yield attributes and yield

To ascertain the role of sulphur and zinc an experiment was conducted by Singh *et al*. (2012) at main campus of ICAR Research Complex of Eastern Region Patna with four levels of both nutrients i.e. sulphur and zinc. Based on three years of experimentation, results revealed that rice plant height is significantly influenced by sulphur and zinc. Tallest plant (101.7 cm) was recorded at maturity with application of 6 kg Zn ha^{-1}. Maximum rice yield (7.63 t ha^{-1}) was recorded with combined application of 30 kg sulphur and 6 kg zinc. Maximum (281.2 kg ha^{-1}) nitrogen uptake was recorded with 6 kg zinc treatment. However highest uptake of P (91.1 kg ha^{-1}) and K (150.4 kg ha^{-1}) was recorded in the plot supplemented with no Zn and sulphur at 40 kg ha^{-1}, respectively. Soil parameters viz., pH, EC and organic carbon content did not influence with S and Zn. N, P, K, S and Zn were affected significantly due to sulphur and zinc nutrition.

A field experiment was conducted by Dixit *et al.* (2012) to study the effect of sulphur and zinc on yield, quality and nutrient uptake by hybrid rice grown in sodic soil. They reported that increasing doses of sulphur and zinc significantly increased their uptake by hybrid rice crop. The interaction effect of sulphur and zinc was found non-significant and the highest grain and straw yields were recorded with application of 40 kg S and 10 kg Zn ha^{-1}. Nitrogen, phosphorus and potassium uptake in crop increased significantly with sulphur and zinc application.

The experiment was conducted by Tarafder *et al*. (2008) conducted an experiment with eight treatments for potato $S_{15}Zn_2$ (T_2, T_4 and T_8), S_8Zn_1 (T_5 and T_6) and S_0Zn_0 (T_1, T_3 and T_7), for boro rice $S_{20}Zn_4$ (T_3, T_5, T_6 and T_7) and S_0Zn_0 (T_1, T_3, T_4 and T_6). The experiment was laid out in a randomized complete block design with three replications. In Boro rice, growth and yield attributes, grain and straw yields responded significantly to S and Zn. The average grain yield varied from 3.51 to 5.27 t ha^{-1} over the treatments. In case of T. aman rice, the grain and straw yields responded significantly to S and Zn.

An experiment was conducted by Rahman *et al*. (2008) at Bangladesh Agricultural University, Mymensingh farm during 2004 Boro season to evaluate the effect of S and Zn on rice (cv. BRRI dhan29). There were seven treatments viz. S_0Zn_0, $S_{10}Zn_0$, $S_{20}Zn_0$, $S_0Zn_{1.5}$, S_0Zn_3, $S_{10}Zn_{1.5}$ and $S_{20}Zn_3$. The subscripts of S and Zn represent the dose in kg ha^{-1}. The highest grain (5.76 t ha^{-1}) and straw (7.32 t ha^{-1}) yields were recorded from $S_{20}Zn_3$ treatment (100% recommended dose). The S_0Zn_0 (control) had the lowest grain yield with 4.35 t ha^{-1} as well as the lowest straw yield with 5.47 t ha^{-1}. The application of both S and Zn fertilizers significantly increased S and Zn contents as well as their uptake over control.

The effect of single and multiple applications of S and Zn in a continuous rice cropping system on loam soil were investigated by Hoque and Jahiruddin (1994) at Mymensingh, Bangladesh. The treatments were S alone, Zn alone and S + Zn, each added to the 1st crop, 1st and 2nd crops or all 3 crops. The rate of S was 20 kg ha^{-1} (gypsum form) and Zn was 10 kg ha^{-1} and reported that crop yields were increased by S but not by generally by Zn.

From the above review of literature it is evident that sulphur and zinc and their combination have a significant influence on yield and yield components of rice. The literature suggests that optimum use of sulphur and zinc increases the grain yield of rice. Reduction in grain yield is mainly attributed by the reduced number of tiller $hill^{-1}$, grains $panicle^{-1}$ and thousand grain weight due to restriction of development of these parameters for the effect of sulphur and zinc.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted to find out the influence of sulphur and zinc on yield of T. aman rice BRRI dhan34. The details of the materials and methods i.e. location of experimental site, soil and climatic condition of the experimental plot, materials used, design of the experiment, data collection procedure and statistical analysis followed in this experiment are presented below under the following headings:

3.1 Description of the experimental site

3.1.1 Experimental period

The experiment was conducted during the period from June to November 2013 during aman season.

3.1.2 Site description

The present piece of research work was conducted in the experimental area of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The location of the site is $23^{0}74^{/}$N latitude and $90^{0}35^{/}$E longitude with an elevation of 8.2 meter from sea level.

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 and 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). Details of the meteorological data of air temperature, relative humidity, rainfall and sunshine hour during the period of the experiment was collected from the Weather Station of Bangladesh, Sher-e-Bangla Nagar, Dhaka and details are presented in Appendix I.

3.1.4 Soil characteristics of the experimental plot

The soil belongs to "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. Soil pH was 5.6 and had organic carbon 0.45%. The experimental area was flat having available irrigation and drainage system and above flood level. The selected plot was medium high land. The details have been presented in Appendix II.

3.2 Experimental details

3.2.1 Planting material

BRRI dhan34 was used as the test crop in this experiment. This variety was developed by Bangladesh Rice Research Institute. It has been recommended for Aman season. The average plant height of the variety is 117 cm. The aromatic grains are small, fine and white. It requires about 135 days for completing its life cycle with an average yield is 3.5 t ha^{-1} (BRRI, 2013).

3.2.2 Treatments

The experiment comprised of two factors

Factor A: Levels of sulphur (3 levels)

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

ii) S_1: 8.0 kg S ha^{-1}

iii) S_2: 12.0 kg S ha^{-1}

Factor B: Levels of zinc (4 levels)

i) Zn_0: 0 kg Zn ha^{-1} (control)

ii) Zn_1: 1.0 kg Zn ha^{-1}

iii) Zn_2: 2.0 kg Zn ha^{-1}

iv) Zn_3: 3.0 kg Zn ha^{-1}

There were in total 12 (3×4) treatment combinations such as 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 and S_2Zn_3.

3.2.3 Experimental design and layout

The factorial experiment was laid out in a randomized complete block design (RCBD) with three replications. The experimental area was divided into three blocks representing the replications to reduce soil heterogenetic effects. Each block was divided into 12 unit plots as treatments with raised bunds around. Thus the total numbers of plots were 36. The unit plot size was 3.0 m × 1.8 m. The distance maintained between two blocks and two plots were 1.0 m and 0.5 m respectively. The layout of the experiment is shown in Figure 1.

3.3 Growing of crops

3.3.1 Seed collection and sprouting

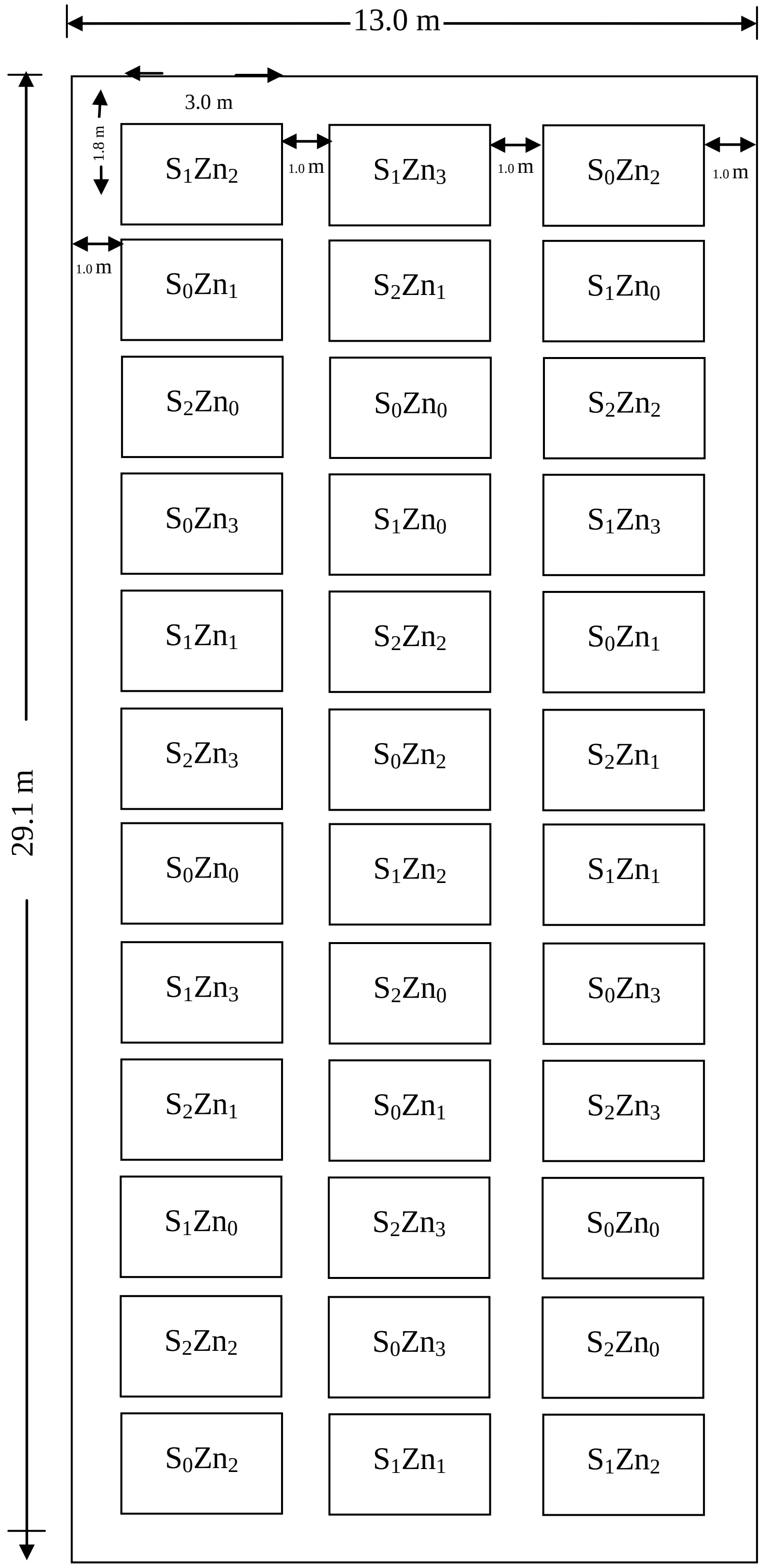
Seeds were collected from BRRI (Bangladesh Rice Research Institute), Gazipur just 20 days ahead of the sowing of seeds in seed bed. Seeds were immersed in water in a bucket for 24 hours. These were then taken out of water and kept in gunny bags. The seeds started sprouting after 48 hours which were suitable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

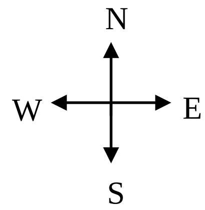
3.3.2 Raising of seedlings

The nursery bed was prepared by puddling with repeated ploughing followed by laddering. The sprouted seeds were sown as uniformly as possible. Irrigation was gently provided to the bed as and 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 second week of July 2013 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. Organic and inorganic manures as indicated below were mixed with the soil of each unit plot.





Plot size: 3.0 m × 1.8 m

Plot spacing: 0.50 m

Between block: 1.00 m

Factors A: Level of sulphur

S_0: 0 kg S ha^{-1}

S_1: 8 kg S ha^{-1}

S_2: 12 kg S ha^{-1}

Factor B: Level of zinc

Zn_0: 0 kg Zn ha^{-1}

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

Figure 1. Layout of the experimental plot

3.3.4 Fertilizers and manure application

The fertilizers N, P, K, S, Zn and B in the form of urea, TSP, MoP, Gypsum, zinc sulphate and borax, respectively were applied. The one third amount of urea and entire amount of TSP, MOP, gypsum, zinc sulphate and borax were applied during the final preparation of land. Rest urea was applied in two equal installments at tillering and panicle initiation stages. The dose and method of application of fertilizers are presented in Table 1.

Table 1. Dose and method of application of fertilizers in rice field

Fertilizers	Dose (ha^{-1})	Application (%)		
		Basal	1st installment	2nd installment
Urea	150 kg	33.33	33.33	33.33
TSP	60 kg	100	--	--
MoP	90 kg	100	--	--
Gypsum	As per treatment	100	--	--
Zinc sulphate	As per treatment	100		
Borax	10 kg	100	--	--

Source: BRRI, 2013 (Adunik Dhaner Chash)

3.3.5 Transplanting of seedling

Twenty five days old seedlings of BRRI dhan34 were carefully uprooted from the seedling nursery and transplanted on 22 July, 2013 in well puddled plot. Three seedlings $hill^{-1}$ were used following a spacing of 20 cm × 20 cm. After one week of transplanting all plots were checked for any missing hill, which was filled up with extra seedlings required.

3.3.6 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

Necessary irrigations were provided to the plots as and when required during the growing period of rice crop.

3.3.6.2 Weeding

The plots were infested with some common weeds, which were removed by uprooting them from the field three times during the cropping season.

3.3.6.3 Insect and pest control

There was no infection of diseases in the field but leaf roller (*Chaphalocrosis medinalis*) was observed in the field, which was controlled by using Malathion @ 1.12 L ha^{-1}.

3.4 Harvesting, threshing and cleaning

The crop was harvested at full maturity on 28 November when 80-90% of the grains were turned into straw color. The harvested crop was bundled separately, properly tagged and brought to threshing floor. Enough care was taken during threshing and cleaning period of rice grain. Fresh weight of rice grain and straw were recorded plot wise from 1 m^2 area. The grains were dried, cleaned and weighed for individual plot. The weight was adjusted to a moisture content of 14%. Yields of rice grain and straw m^{-2} were recorded and converted to t ha^{-1}.

3.5 Data collection on yield components and yield

3.5.1 Plant height

The height of plant was recorded in centimeter (cm) at the time of 30, 45, 60, 75 days after transplanting and at harvesting stage. Data were recorded as the average of 10 plants selected at random from the inner rows of each plot. The height was measured from the ground level to the tip of the panicle/flag leaf.

3.5.2 Effective tillers $hill^{-1}$

The total number of effective tillers $hill^{-1}$ was counted as the number of panicle bearing tiller during harvesting. Data on effective tillers $hill^{-1}$ were counted from 10 selected hills and average value was recorded.

3.5.3 Non-effective tillers $hill^{-1}$

The total number of non-effective tiller $hill^{-1}$ was counted as the number of non-panicle bearing tiller during harvesting. Data on non effective tiller $hill^{-1}$ were counted from 10 selected hills and average value was recorded.

3.5.4 Total tillers hill^{-1}

The total number of tiller hill^{-1} was counted as the number of effective tillers hill^{-1} and non-effective tillers hill^{-1}. Data on total tillers hill^{-1} were counted from 10 selected hills and average value was recorded.

3.5.5 Length of panicle

The length of panicle was measured with a meter scale from 10 selected plants and the average value was recorded as per plant.

3.5.6 Filled grains panicle^{-1}

The total numbers of filled grain was collected randomly from selected 10 plants of a plot on the basis of grain in the spikelet and then average numbers of filled grains panicle^{-1} was recorded.

3.5.7 Unfilled grains panicle^{-1}

The total numbers of unfilled grain was collected randomly from selected 10 plants of a plot on the basis of not grain in the spikelet and then average numbers of unfilled grains panicle^{-1} was recorded.

3.5.8 Total grains panicle^{-1}

The total numbers of grain was collected randomly from selected 10 plants of a plot by adding filled and unfilled grain and then average numbers of grains panicle^{-1} was recorded.

3.5.9 Weight of 1000-grain

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

3.5.10 Grain yield

Grains obtained from each unit plot were sun-dried and weighed carefully. The dry weight of grains of central 1 m^2 area and five sample plants were added to the respective unit plot yield to record the final grain yield plot^{-1} and finally converted to ton hectare^{-1} (t ha^{-1}).

3.5.11 Straw yield

Straw obtained from each unit plot were sun-dried and weighed carefully. The dry weight of straw of central 1 m^2 area and five sample plants were added to the respective unit plot yield to record the final straw yield $plot^{-1}$ and finally converted to ton $hectare^{-1}$ ($t\ ha^{-1}$).

3.5.12 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.

3.5.13 Harvest index

Harvest index 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 Chemical analysis of plant samples

3.6.1 Collection of plant samples

Grain and straw samples were collected after threshing and finely ground by using a Wiley-Mill with stainless contact points to pass through a 60-mesh sieve. The samples were stored in plastic vial for analyses of N, P, K, S and Zn.

3.6.2 Preparation of plant samples

The plant samples were dried in an oven at 70^0C for 72 hours and then ground by a grinding machine to pass through a 20-mesh sieve. The grain and straw samples were analyzed for determination of N, P, K, S and Zn concentrations as follows:

3.6.3 Digestion of plant samples with sulphuric acid for N

For the determination of nitrogen an amount of 0.2 g oven dry, ground sample were taken in a micro kjeldahl flask. 1.1 g catalyst mixture (K_2SO_4: $CuSO_4$. $5H_2O$: Se in the ratio of 100: 10: 1), and 5 ml conc. H_2SO_4 were added. The flasks were heating at 120^0C and added 2.5 ml 30% H_2O_2 then heated was continued at 180^0C until the digests became clear and colorless. After cooling, the content was taken into a 100 ml volumetric flask and the volume was made up to the mark with de-ionized water. A reagent blank was prepared in a similar manner. Nitrogen in the digest was estimated by distilling the digest with 10 N NaOH followed by titration of the distillate trapped in H_3BO_3 indicator solution with 0.01N H_2SO_4.

3.6.4 Digestion of plant samples with nitric-perchloric acid for P, K, S and Zn

A sub sample weighing 0.5 g was transferred into a dry, clean 100 ml digestion vessel. Ten ml of di-acid (HNO_3: $HClO_4$ in the ratio 2:1) mixture was added to the flask. After leaving for a while, the flasks were heated at a temperature slowly raised to 200^0C. Heating were stopped when the dense white fumes of $HClO_4$ occurred. The content of the flask were boiled until they became clean and colorless. After cooling, the content was taken into a 100 ml volumetric flask and the volume was made up to the mark with de-ionized water. P, K, S and Zn were determined from this digest.

3.6.5 Determination of P, K, S and Zn from plant samples

3.6.5.1 Phosphorus

Phosphorus in the digest was determined by using 1 ml for grain sample and 2 ml for straw sample from 100 ml extract was then determined by Vanado molybdate method and the color intensity were measured colorimetrically at 660 nm wavelength and readings were calibrated with the standard P curve (Page *et al.*, 1982).

3.6.5.2 Potassium

Five milli-liter of digest sample for the grain and 10 ml for the straw were taken and diluted 50 ml volume to make desired concentration so that the absorbance of sample were measured within the range of standard solutions. The absorbance was measured by atomic absorption spectrometer.

3.6.5.3 Sulphur

Sulphur content was determined from the digest of the plant samples (grain and straw) with $CaCl_2$ (0.15%) solution as described by (Page *et al*., 1982). The digested S was determined by developing turbidity by adding acid seed solution (20 ppm S as K_2SO_4 in 6N HCl) and $BaCl_2$ crystals. The intensity of turbidity was measured by atomic absorption spectrophotometer at 420 nm wavelengths (Hunter, 1984).

3.6.5.4 Zinc

Zinc content was determined from the digest of the grain and straw samples by developing turbidity by adding $BaCl_2$ seed solution. The intensity of turbidity was measured by atomic absorption spectrophotometer at 420 nm wavelengths (Hunter, 1984).

3.7 Nutrient uptake

After chemical analysis of grain and straw samples the nutrient contents were calculated and from the value of nutrient contents, nutrient uptakes were also calculated by following formula:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{Yield (kg ha}^{-1}\text{)}}{100}$$

3.8 Post harvest soil sampling

After harvest of crop, soil samples were collected from each plot at a depth of 0 to 15 cm. Soil samples of each plot was air-dried, crushed and passed through a two mm (10 meshes) sieve. The soil samples were kept in plastic container to determine the physical and chemical properties of soil.

3.9 Soil analysis

Soil samples were analyzed for both physical and chemical characteristics viz. pH, organic matter S, and Zn contents. The soil samples were analyzed by the following standard methods as follows:

3.9.1 Soil pH

Soil pH was measured with the help of a glass electrode pH meter, the soil water ratio being maintained at 1: 2.5 as described by Page *et al.*, 1982.

3.9.2 Organic matter

Organic carbon in soil sample was determined by wet oxidation method (Page *et al.*, 1982). The underlying principle was used to oxidize the organic matter with an excess of 1N $K_2Cr_20_7$ in presence of conc. H_2SO_4 and conc. H_3PO_4 and to titrate the excess $K_2Cr_20_7$ solution with 1N $FeSO_{4.}$ To obtain the content of organic matter was calculated by multiplying the percent organic carbon by 1.73 (Van Bemmelen factor) and the results were expressed in percentage.

3.9.3 Available sulphur

Available S content was determined by extracting the soil with $CaCl_2$ (0.15%) solution as described by Page *et al*., 1982. The extractable S was determined by developing turbidity by adding acid solution (20 ppm S as K_2SO_4 in 6N HCl) and $BaCl_2$ crystals. The intensity of turbidity was measured by atomic absorption spectrophotometer at 420 nm wavelengths.

3.9.4 Available Zinc

Available S content was determined by developing turbidity by adding $BaCl_2$ solution. The intensity of turbidity was measured by atomic absorption spectrophotometer at 420 nm wavelengths (Hunter, 1984).

3.10 Statistical analysis

The data obtained for different parameters were statistically analyzed to find out the significant difference of different treatments on growth, yield and nutrient content of transplanted aman rice BRRI dhan34. The mean values of all the characters were calculated and analysis of variance was performed by the ‘F’ (variance ratio) test. The significance of the differences among the treatment means were estimated by the Duncan’s Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

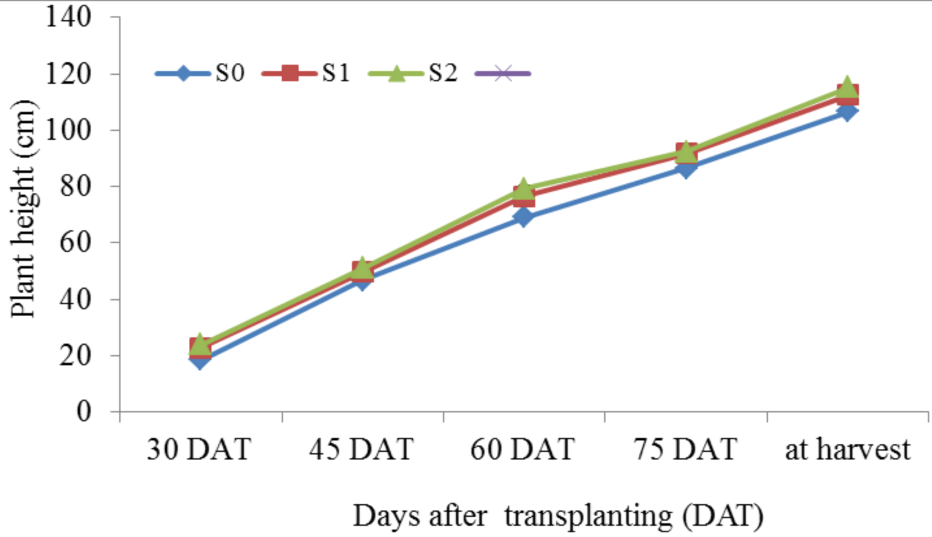
RESULTS AND DISCUSSION

The experiment was conducted to find out the influence of sulphur and zinc on yield of transplanted (T.) aman rice. Data on different growth parameter & yield of rice, nutrient concentration in grain & straw, nutrient uptake by grain & straw and characteristics of post harvest soil was recorded. The analyses of variance (ANOVA) of the data on different recorded parameters are presented in Appendix III-X. The results have been presented and discusses with the help of table and graphs and possible interpretations are given under the following headings:

4.1 Yield contributing characters and yield of rice

4.1.1 Plant height

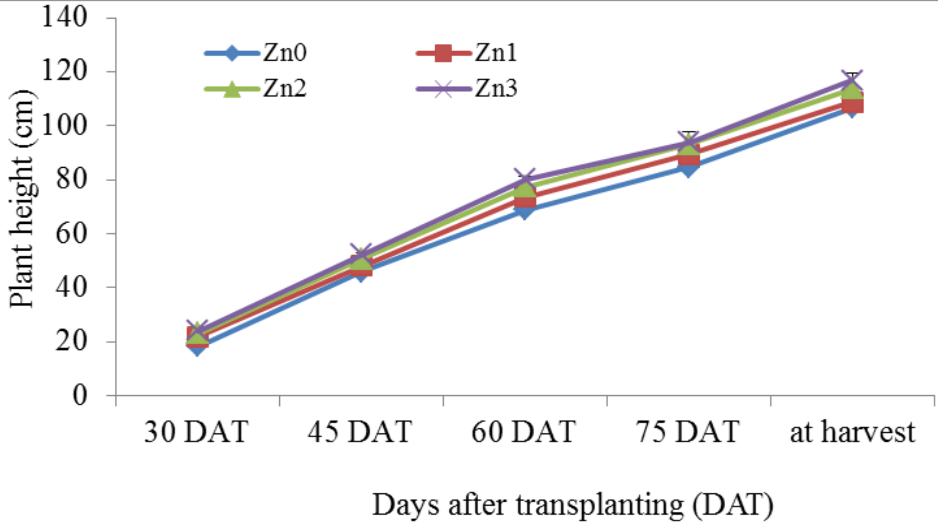
Plant height of BRRI dhan34 varied significantly for different levels of sulphur at 30, 45, 60, 75 DAT and harvest (Figure 2). At 30, 45, 60, 75 DAT and harvest, the tallest plant (23.93, 50.99, 79.40, 92.46 and 115.27 cm, respectively) was observed from S_2 (12.0 kg S ha^{-1}), which was statistically identical (22.92, 49.78, 76.65, 91.72 and 112.48 cm, respectively) with S_1 (8.0 kg S ha^{-1}), whereas the shortest plant (18.62, 46.86, 69.04, 86.63 and 106.60 cm, respectively) was observed from S_0 (0 kg S ha^{-1}). Data revealed that with the increase of application of sulphur nutrients plant height showed increasing trend. Among the essential elements, sulphur is very much beneficial for the growth and development of rice plant and is one of the major essential nutrient elements involved in the synthesis of chlorophyll, certain amino acids like methionine, cystine, cysteine and some plant hormones such as thiamine and biotin which influences vegetative growth of rice (Rahman *et al*., 2007). Singh and Singh (2002) reported that plant height of rice was significant with increasing levels of S up to 40 kg S ha^{-1} but Chandel *et al*. (2003) reported that plant height increases increasing S levels up to 45 kg ha^{-1}, whereas Rahman *et al*. (2009) reported that plant height BRRI dhan41 was not to be significantly responded to different levels of S fertilizer.



S_0: 0 kg S ha^{-1} (control) S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Figure 2. Effect of different levels of sulphur on plant height of BRRI dhan34



Zn_0: 0 kg Zn ha^{-1} (control) Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1} Zn_3: 3.0 kg Zn ha^{-1}

Figure 3. Effect of different levels of zinc on plant height of BRRI dhan34

Statistically significant variation was recorded for plant height of BRRI dhan34 due to different levels of zinc at 30, 45, 60, 75 days after transplanting (DAT) and harvest (Figure 3). Data revealed that at 30, 45, 60, 75 DAT and harvest, the tallest plant (23.92, 52.24, 80.23, 93.78 and 116.73 cm, respectively) was recorded from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (23.07, 50.62, 77.46, 93.12 and 113.78 cm, respectively) with Zn_2 (2.0 kg Zn ha^{-1}) and closely followed (21.85, 48.00, 73.64, 89.48 and 108.70 cm, respectively) by Zn_1 (1.0 kg Zn ha^{-1}), while the shortest plant (18.46, 45.97, 68.79, 84.71 and 106.59 cm, respectively) was found from Zn_0 i.e. 0 kg Zn ha^{-1}. It was revealed that with the increase of zinc fertilizer, plant height increased upto the highest of Zn (Chaudhary *et al*., 2007). Zinc ensured the availability of other macro and micro nutrients that created a favorable condition for the growth of BRRI dhan34 with optimum vegetative growth and the ultimate results was the tallest plant (Slaton *et al*., 2005). Cheema *et al*. (2006) reported that plant height, showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}. Yadi *et al.* (2012) observed tallest plant in 4 kg Zn ha^{-1} and the least of those was obtained in control treatment.

Interaction effect of different levels of sulphur and zinc showed significant variation on plant height of BRRI dhan34 at 30, 45, 60, 75 days after transplanting (DAT) and harvest (Table 2). At 30, 45, 60, 75 DAT and harvest, the tallest plant (26.65, 54.48, 87.32, 98.67 and 122.53 cm, respectively) was observed from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}) and the shortest plant (16.89, 45.09, 63.66, 81.05 and 103.81 cm) was found from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination. Singh *et al*. (2012) reported that rice plant height is significantly influenced by sulphur and zinc and the tallest plant (101.7 cm) was recorded at maturity with application of 6 kg Zn ha^{-1}. Dixit *et al*. (2012) reported positive response of hybrid rice to zinc application up to the zinc dose @ 10 kg ha^{-1} in respect of plant height.

Table 2. Interaction effect of sulphur and zinc on plant height of T. aman rice

Treatment	Plant height (cm) at				
	30 DAT	45 DAT	60 DAT	75 DAT	at harvest
S_0Zn_0	16.89 g	45.09 f	63.66 d	81.05 e	103.81 e
S_0Zn_1	18.48 fg	45.26 f	67.13 cd	84.79 de	105.53 de
S_0Zn_2	18.21 fg	46.61 def	73.22 bcd	84.95 de	104.46 e
S_0Zn_3	20.91 de	50.50 abcd	72.15 bcd	89.03 bcde	112.59 cd
S_1Zn_0	19.70 ef	45.73 ef	67.21cd	85.33 de	107.89 de
S_1Zn_1	22.79 cd	49.07 cdef	76.03 bc	87.40 cde	111.11 cde
S_1Zn_2	24.99 abc	52.55 abc	82.14 ab	96.43 abc	115.87 abc
S_1Zn_3	24.21 bc	51.75 abc	81.21 ab	97.72 ab	115.07 bc
S_2Zn_0	18.78 efg	45.57 ef	65.94 cd	87.75 cde	107.43 de
S_2Zn_1	24.27 bc	49.85 bcde	77.75 ab	92.02 abcd	109.47 cde
S_2Zn_2	26.01 ab	54.05 ab	86.59 a	98.12 ab	121.67 ab
S_2Zn_3	26.65 a	54.48 a	87.32 a	98.67 a	122.53 a
Significance level	0.01	0.05	0.01	0.01	0.05
CV(%)	5.77	4.76	7.48	5.38	3.42

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

4.1.2 Number of effective tillers hill^{-1}

Different levels of sulphur showed statistically significant differences in terms of number of effective tillers hill^{-1} (Table 3). The maximum number of effective tillers hill^{-1} (15.07) was recorded from S_2 (12.0 kg S ha^{-1}), which was statistically identical (14.64) with S_1 (8.0 kg S ha^{-1}), while the minimum number (11.87) was found from S_0 (0 kg S ha^{-1}). Rahman *et al.* (2009) reported that effective tillers hill^{-1} significantly increased to different levels of S.

Number of effective tillers hill^{-1} varied significantly due to different levels of zinc (Table 3). The maximum number of effective tillers hill^{-1} (15.31) was obtained from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (14.60) with Zn_2 (2.0 kg Zn ha^{-1}) and closely followed (13.91) by Zn_1 (1.0 kg Zn ha^{-1}) but the minimum number (11.61) from Zn_0 i.e. 0 kg Zn ha^{-1}. Cheema *et al.* (2006) reported that panicle bearing tillers showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}.

Statistically significant variation was recorded in terms of number of effective tillers hill^{-1} of BRRI dhan34 due to the interaction effect of different levels of sulphur and zinc (Table 4). The maximum number of effective tillers hill^{-1} (16.73) was recorded from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), whereas the minimum number (11.00) was observed from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

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

Number of non-effective tillers hill^{-1} showed statistically significant differences for different levels of sulphur (Table 3). Data revealed that the maximum number of non-effective tillers hill^{-1} (3.37) was found from S_2 (12.0 kg S ha^{-1}), which was statistically identical (3.28) with S_1 (8.0 kg S ha^{-1}) and the minimum number (2.50) was recorded from S_0 (0 kg S ha^{-1}). Singh and Singh (2014) reported highest non-effective tillers hill^{-1} with the application of sulphur at 45 kg ha^{-1}.

Table 3. Effect of sulphur and zinc on yield contributing characters of T. aman rice

Treatment	Number of effective tiller $hill^{-1}$	Number of non-effective tiller $hill^{-1}$	Length of panicle (cm)	Number of filled grain $panicle^{-1}$	Number of unfilled grain $panicle^{-1}$
Levels of sulphur					
S_0	11.87 b	2.50 b	22.29 c	71.72 b	6.42 b
S_1	14.64 a	3.28 a	24.45 b	81.88 a	7.82 a
S_2	15.07 a	3.37 a	25.81 a	83.90 a	7.97 a
Significance level	0.01	0.01	0.01	0.01	0.01
Levels of zinc					
Zn_0	11.61 c	2.33 c	20.80 c	72.62 c	6.51 c
Zn_1	13.91 b	3.00 b	23.08 b	78.20 b	7.27 b
Zn_2	14.60 ab	3.40 a	25.80 a	81.13 ab	7.67 ab
Zn_3	15.31 a	3.47 a	27.08 a	84.71 a	8.16 a
Significance level	0.01	0.01	0.01	0.01	0.01
CV(%)	5.54	6.87	6.50	5.77	8.02

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

Table 4. Interaction effect of sulphur and zinc on yield contributing characters of of T. aman rice

Treatment	Number of effective tiller $hill^{-1}$	Number of non-effective tiller $hill^{-1}$	Length of panicle (cm)	Number of filled grain $panicle^{-1}$	Number of unfilled grain $panicle^{-1}$
S_0Zn_0	11.00 e	2.13 e	20.23 f	65.27 d	5.87 d
S_0Zn_1	11.60 e	2.40 de	21.76 def	69.07 d	6.27 d
S_0Zn_2	11.20 e	2.67 cd	20.69 ef	72.80 cd	6.60 d
S_0Zn_3	13.67 d	2.80 c	25.49 bc	79.73 bc	6.93 cd
S_1Zn_0	11.97 e	2.40 de	20.91 ef	73.33 cd	6.60 d
S_1Zn_1	14.93 cd	3.27 b	23.52 cde	82.33 ab	7.73 bc
S_1Zn_2	16.13 abc	3.73 a	27.31 ab	88.00 ab	8.53 ab
S_1Zn_3	15.53 abc	3.73 a	26.08 bc	83.87 ab	8.40 ab
S_2Zn_0	11.87 e	2.47 cde	20.27 f	71.73 cd	6.33 d
S_2Zn_1	15.20 bc	3.33 b	23.95 cd	83.20 ab	7.80 bc
S_2Zn_2	16.47 ab	3.80 a	29.39 a	90.13 a	8.60 ab
S_2Zn_3	16.73 a	3.87 a	29.65 a	90.53 a	9.13 a
Significance level	0.01	0.05	0.01	0.01	0.01
CV(%)	5.54	6.87	6.50	5.77	8.02

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

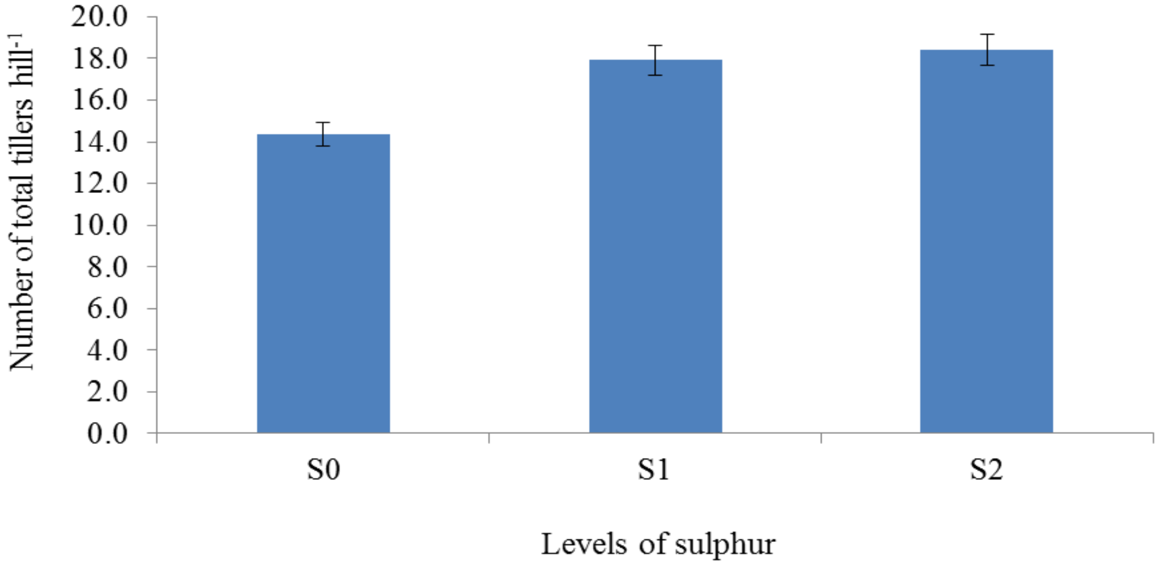
Different levels of zinc varied significantly in terms of number of non-effective tillers hill^{-1} (Table 3). The maximum number of non-effective tillers hill^{-1} (3.47) was attained from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (3.40) with Zn_2 (2.0 kg Zn ha^{-1}) and closely followed (3.00) by Zn_1 (1.0 kg Zn ha^{-1}), whereas the minimum number (2.33) was observed from Zn_0 i.e. 0 kg Zn ha^{-1}. Khan *et al*. (2007) reported that Zn significantly influenced non-effective tillers.

Number of non-effective tillers hill^{-1} of BRRI dhan34 showed significant variation due to the interaction effect of different levels of sulphur and zinc (Table 4). The maximum number of non-effective tillers hill^{-1} (3.87) was recorded from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), while the minimum number (2.13) was found from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

4.1.4 Number of total tillers hill^{-1}

Different levels of sulphur varied significantly for number of total tillers hill^{-1} (Figure 4). The maximum number of total tillers hill^{-1} (18.43) was observed from S_2 (12.0 kg S ha^{-1}), which was statistically identical (17.92) with S_1 (8.0 kg S ha^{-1}), while the minimum number (14.37) was recorded from S_0 (0 kg S ha^{-1}). Sulphur is required early in the growth of rice plants. If it is limiting during early growth, then tiller number reduced (Blair and Lefroy, 1987). Singh and Singh (2002) reported that tillers m^{-2} row length was significant with increasing levels of S up to 40 kg S ha^{-1}.

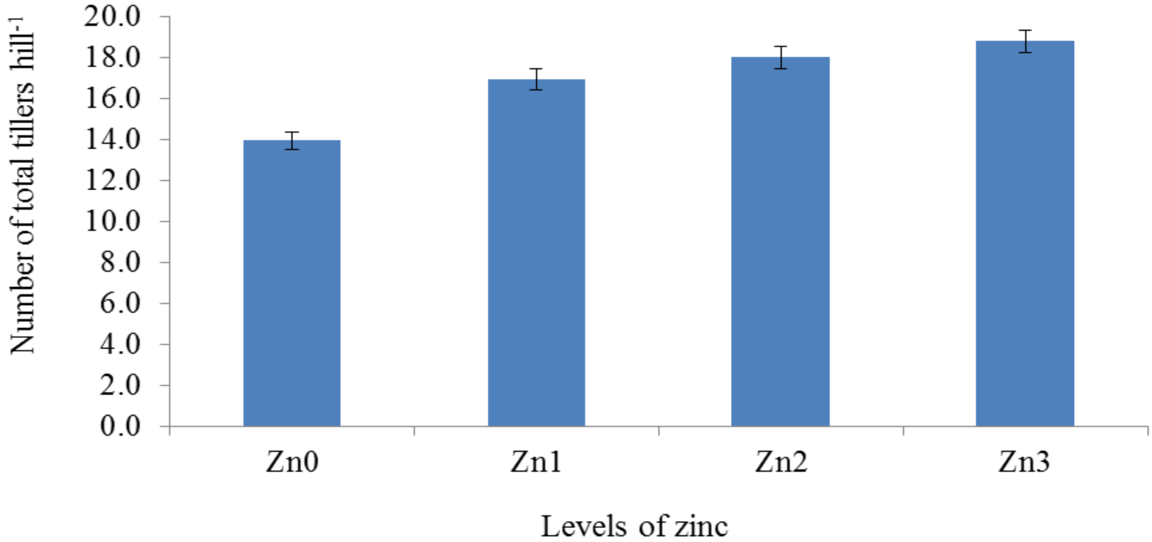
Statistically significant variation was recorded for number of total tillers hill^{-1} due to different levels of zinc (Figure 5). The maximum number of total tillers hill^{-1} (18.78) was found from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (18.00) with Zn_2 (2.0 kg Zn ha^{-1}) and closely followed (16.91) by Zn_1 (1.0 kg Zn ha^{-1}), again the minimum number (13.94) from Zn_0 i.e. 0 kg Zn ha^{-1}. Ullah *et al*. (2001) obtained the highest number of tillers (10.600 hill^{-1}) with 20 kg zinc sulfate ha^{-1}.



S_0: 0 kg S ha^{-1} (control) S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Figure 4. Effect of different levels of sulphur on number of total tillers hill^{-1} of BRRI Dhan34



Zn_0: 0 kg Zn ha^{-1} (control) Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1} Zn_3: 3.0 kg Zn ha^{-1}

Figure 5. Effect of different levels of zinc on number of total tillers hill^{-1} of BRRI dhan34

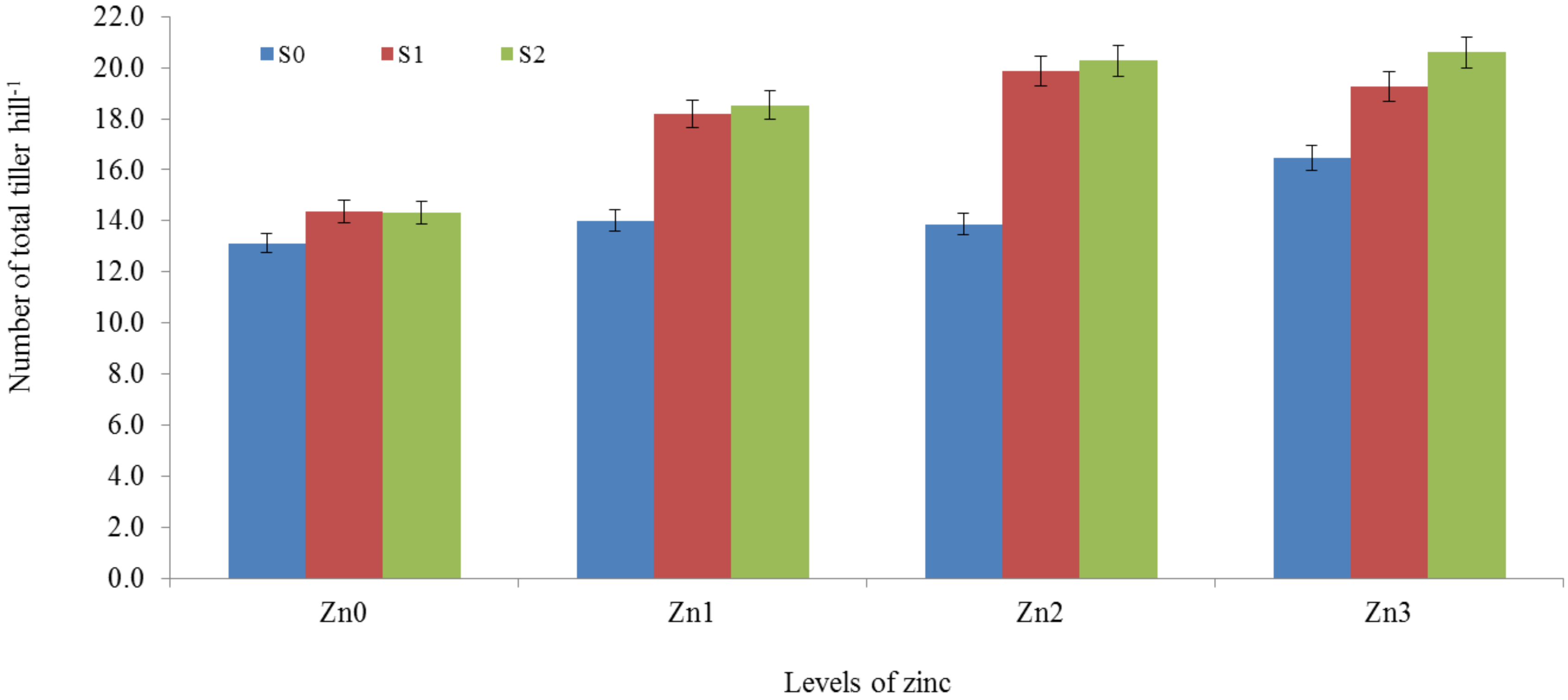
Interaction effect of different levels of sulphur and zinc showed significant variation on number of total tillers $hill^{-1}$ of BRRI dhan34 (Figure 6). The maximum number of total tillers $hill^{-1}$ (20.60) was observed from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}) but the minimum number (13.13) was found from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

4.1.5 Length of panicle

Statistically significant variation was recorded in terms of length of panicle due to different levels of sulphur (Table 3). The longest panicle (25.81 cm) was recorded from S_2 (12.0 kg S ha^{-1}), which was statistically identical (24.45 cm) with S_1 (8.0 kg S ha^{-1}), whereas the shortest panicle (22.29 cm) was found from S_0 (0 kg S ha^{-1}). Singh and Singh (2002) reported that panicle length was significant with increasing levels of S up to 40 kg S ha^{-1}. Rahman *et al*. (2009) reported that panicle length of BRRI dhan41 was not significantly responded to different levels of S.

Length of panicle showed statistically significant variation for different levels of zinc (Table 3). The longest panicle (27.08 cm) was attained from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (25.80 cm) with Zn_2 (2.0 kg Zn ha^{-1}) and closely followed (23.08 cm) by Zn_1 (1.0 kg Zn ha^{-1}), while the shortest panicle (20.80 cm) was obtained from Zn_0 i.e. 0 kg Zn ha^{-1}. Cheema *et al*. (2006) reported that panicle size showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}. Mustafa *et al*. (2011) recorded longest panicle with basal application at the rate 25 kg ha^{-1}.

Due to the interaction effect of different levels of sulphur and zinc the length of panicle of BRRI dhan34 varied significantly (Table 4). The longest panicle (29.65 cm) was obtained from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), again the shortest panicle (20.23 cm) was observed from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.



S_0: 0 kg S ha^{-1} (control) S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control) Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1} Zn_3: 3.0 kg Zn ha^{-1}

Figure 6. Interaction effect of different levels of sulphur and zinc on number of total tiller hill^{-1} of BRRI dhan34

4.1.6 Number of filled grains panicle^{-1}

Number of filled grains panicle^{-1} varied significantly for different levels of sulphur (Table 3). The maximum number of filled grains panicle^{-1} (83.90) was found from S_2 (12.0 kg S ha^{-1}), which was statistically identical (81.88) with S_1 (8.0 kg S ha^{-1}), whereas the minimum number (71.72) was recorded from S_0 (0 kg S ha^{-1}). Rahman *et al*. (2009) reported that filled grain panicle^{-1} significantly responded to different levels of S.

Statistically significant variation was recorded for number of filled grains panicle^{-1} due to different levels of zinc (Table 3). The maximum number of filled grains panicle^{-1} (84.71) was observed from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (81.13) with Zn_2 (2.0 kg Zn ha^{-1}) and closely followed (78.20) by Zn_1 (1.0 kg Zn ha^{-1}), while the minimum number (72.62) from Zn_0 i.e. 0 kg Zn ha^{-1}. Khan *et al*. (2007) reported that increasing levels of Zn significantly influenced yield components of rice.

Interaction effect of different levels of sulphur and zinc showed significant variation on number of filled grains panicle^{-1} of BRRI dhan34 (Table 4). The maximum number of filled grains panicle^{-1} (90.53) was recorded from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}). On the other hand the minimum number (65.27) was observed from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

4.1.7 Number of unfilled grains panicle^{-1}

Different levels of sulphur showed statistically significant differences in terms of number of unfilled grains panicle^{-1} (Table 3). The maximum number of unfilled grains panicle^{-1} (7.97) was observed from S_2 (12.0 kg S ha^{-1}), which was statistically identical (7.82) with S_1 (8.0 kg S ha^{-1}) and the minimum number (6.42) was observed from S_0 (0 kg S ha^{-1}).

Number of unfilled grains panicle^{-1} varied significantly due to different levels of zinc (Table 3). The maximum number of unfilled grains panicle^{-1} (8.16) was recorded from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (7.67) with Zn_2

(2.0 kg Zn ha^{-1}) and closely followed (7.27) by Zn_1 (1.0 kg Zn ha^{-1}), while the minimum number (6.51) from Zn_0 i.e. 0 kg Zn ha^{-1}.

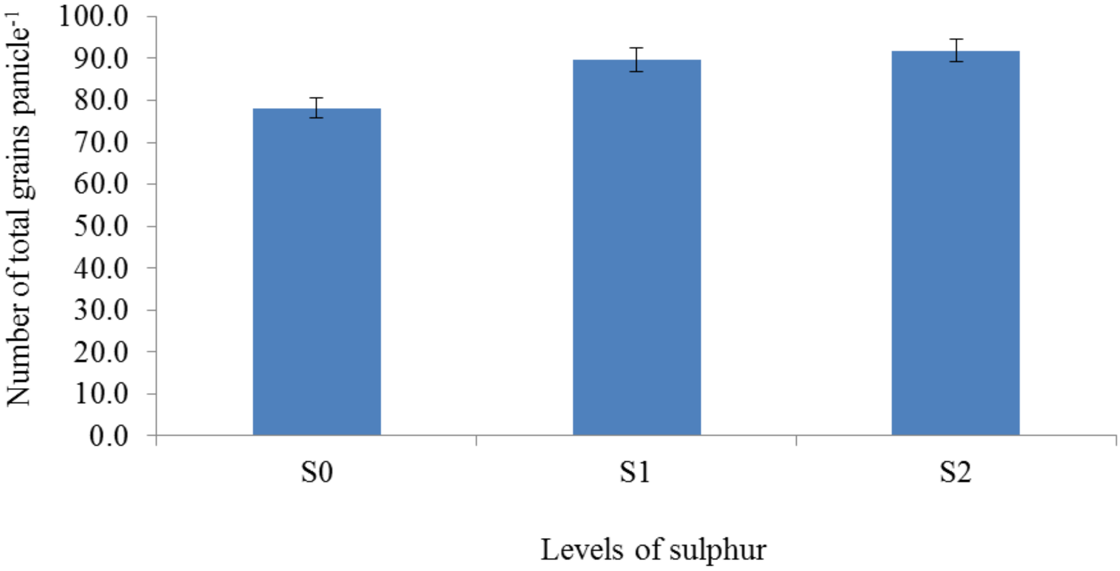
Statistically significant variation was recorded due to the interaction effect of different levels of sulphur and zinc on number of unfilled grains $panicle^{-1}$ (Table 4). The maximum number of unfilled grains $panicle^{-1}$ (9.13) was observed from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), again the minimum number (5.87) was found from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

4.1.8 Number of total grains $panicle^{-1}$

Statistically significant variation was observed in terms of number of total grains $panicle^{-1}$ due to different levels of sulphur (Figure 7). Data revealed that the maximum number of total grains $panicle^{-1}$ (91.87) was recorded from S_2 (12.0 kg S ha^{-1}), which was statistically identical (89.70) with S_1 (8.0 kg S ha^{-1}), while the minimum number (78.13) was found from S_0 (0 kg S ha^{-1}). Singh and Singh (2002) reported that grains panicle $^{-1}$ was significant with increasing levels of S up to 40 kg S ha^{-1}.

Number of total grains $panicle^{-1}$ showed statistically significant differences due to different levels of zinc (Figure 8). The maximum number of total grains $panicle^{-1}$ (92.87) was observed from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (88.80) with Zn_2 (2.0 kg Zn ha^{-1}) and closely followed (85.47) by Zn_1 (1.0 kg Zn ha^{-1}), again the minimum number (79.13) was attained from Zn_0 i.e. 0 kg Zn ha^{-1}.

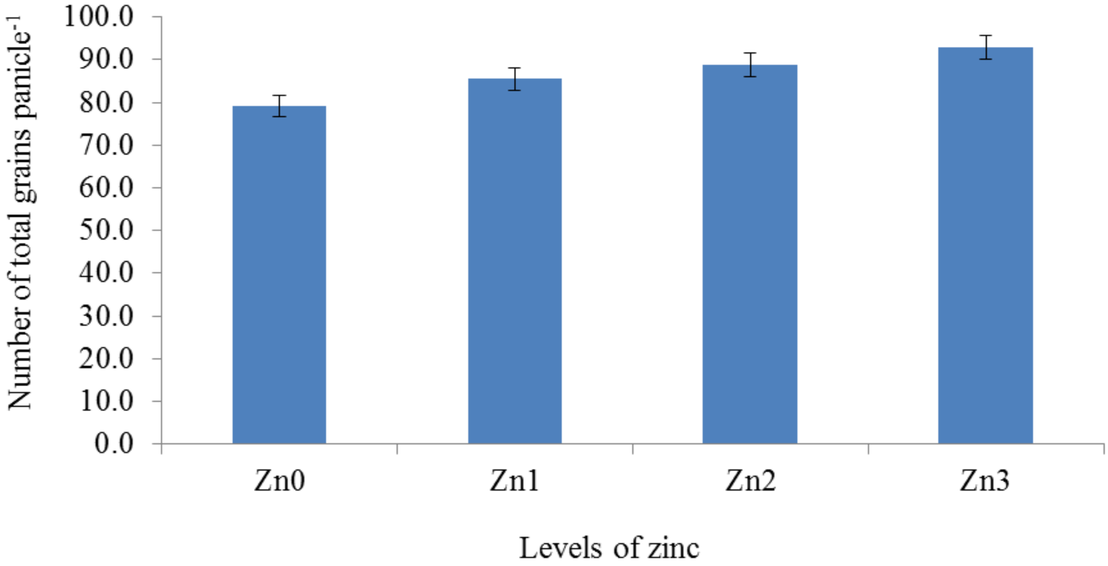
Interaction effect of different levels of sulphur and zinc varied significantly in terms of number of total grains $panicle^{-1}$ of BRRI dhan34 (Figure 9). The maximum number of total grains $panicle^{-1}$ (99.67) was obtained from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), whereas the minimum number (71.13) was recorded from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.



S_0: 0 kg S ha^{-1} (control) S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

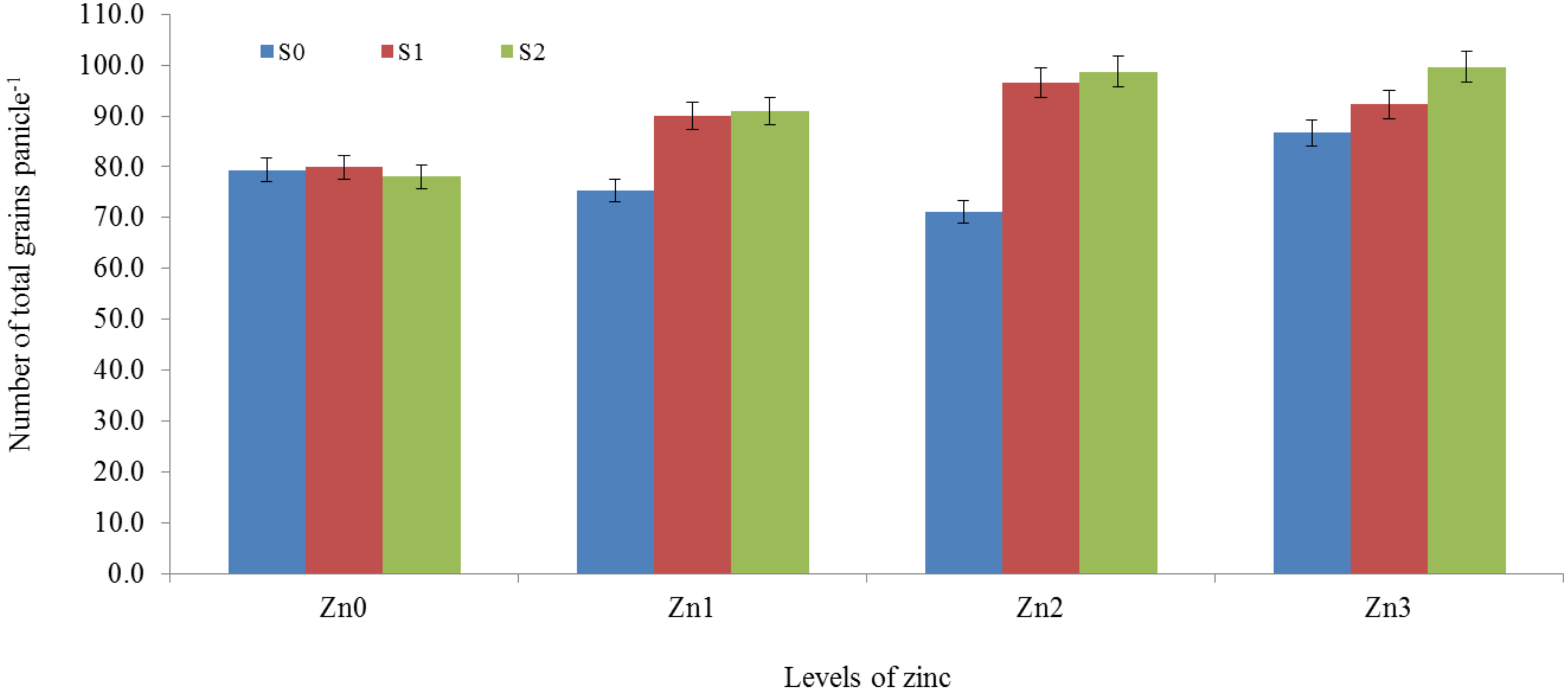
Figure 7. Effect of different levels of sulphur on number of total grains panicle^{-1} of BRRI Dhan34



Zn_0: 0 kg Zn ha^{-1} (control) Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1} Zn_3: 3.0 kg Zn ha^{-1}

Figure 8. Effect of different levels of zinc on number of total grains panicle^{-1} of BRRI dhan34



S_0: 0 kg S ha^{-1} (control) S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control) Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1} Zn_3: 3.0 kg Zn ha^{-1}

Figure 9. Interaction effect of different levels of sulphur and zinc on number of total grains panicle^{-1} of BRRI dhan34

4.1.9 Weight of 1000-grains

Weight of 1000-grains varied significantly for different levels of sulphur (Table 5). The highest weight of 1000-grains (21.58 g) was found from S_2 (12.0 kg S ha^{-1}), which was statistically identical (20.63 g) with S_1 (8.0 kg S ha^{-1}), while the lowest weight (19.65 g) was attained from S_0 (0 kg S ha^{-1}). Rahman *et al*. (2009) reported that 1000-grain weight of BRRI dhan41 significantly increased for S application.

Statistically significant variation was recorded for weight of 1000-grains due to different levels of zinc (Table 5). The highest weight of 1000-grains (21.93 g) was recorded from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (21.13 g) with Zn_2 (2.0 kg Zn ha^{-1}) and closely followed (20.20 g) by Zn_1 (1.0 kg Zn ha^{-1}) and the lowest weight (19.22 g) control (0 kg Zn ha^{-1}). Ullah *et al*. (2001) found the highest 1000-grain weight (28.700 g), from 20 kg zinc sulfate ha^{-1}.

Interaction effect between sulphur and zinc showed significant variation on for 1000-grains weight of BRRI dhan34 (Table 6). The highest weight of 1000-grains (23.51 g) was recorded from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), whereas the lowest weight (18.16 g) was observed from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

4.1.10 Grain yield ha^{-1}

Due to the different levels of sulphur grain yield ha^{-1} varied significantly under the present trial (Table 5). The highest grain yield (3.48 t ha^{-1}) was found from S_2 (12.0 kg S ha^{-1}), which was statistically identical (3.34 t ha^{-1}) with S_1 (8.0 kg S ha^{-1}), again the lowest grain yield (2.46 t ha^{-1}) was attained from S_0 (0 kg S ha^{-1}). Mrinal and Sharma (2008) reported that grain yield of rice increased significantly with increasing levels of sulphur up to 30 kg S ha^{-1}. Rahman *et al*. (2009) reported that grain yield of BRRI dhan41 significantly responded to different levels of S. Jawahar and Vaiyapuri (2011) reported that sulphur at 45 kg ha^{-1} produced the higher grain yield of rice.

Table 5. Effect of sulphur and zinc on the yield of T. aman rice

Treatment	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Levels of sulphur					
S_0	19.65 b	2.46 b	4.06 b	6.52 b	37.73 b
S_1	20.63 ab	3.34 a	4.75 a	8.09 a	41.29 a
S_2	21.58 a	3.48 a	4.83 a	8.30 a	41.88 a
Significance level	0.01	0.01	0.01	0.01	0.01
Levels of zinc					
Zn_0	19.22 c	2.35 c	4.01 c	6.37 c	36.95 b
Zn_1	20.20 bc	3.08 b	4.47 b	7.54 b	40.79 a
Zn_2	21.13 ab	3.37 a	4.80 ab	8.17 a	41.25 a
Zn_3	21.93 a	3.57 a	4.91 a	8.48 a	42.10 a
Significance level	0.01	0.01	0.01	0.01	0.01
CV(%)	6.32	5.31	6.21	4.71	4.04

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

Table 6. Interaction effect of sulphur and zinc on the yield of T. aman rice

Treatment	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
S_0Zn_0	18.16 e	2.13 f	3.88 d	6.01 e	35.44 d
S_0Zn_1	19.51 de	2.30 ef	3.98 d	6.28 de	36.62 cd
S_0Zn_2	19.56 de	2.55 de	3.97 d	6.52 de	39.11 abc
S_0Zn_3	21.37 abcd	2.86 d	4.23 cd	7.09 d	40.34 ab
S_1Zn_0	19.23 de	2.43 ef	4.04 d	6.47 de	37.56 bcd
S_1Zn_1	20.30 cde	3.41 c	4.72 abc	8.14 c	41.94 ab
S_1Zn_2	22.08 abc	3.68 abc	5.10 ab	8.78 abc	41.91 ab
S_1Zn_3	20.90 bcd	3.76 ab	5.13 ab	8.89 ab	42.29 a
S_2Zn_0	18.86 de	2.50 def	3.93 d	6.42 de	38.88 abcd
S_2Zn_1	20.79 bcd	3.42 bc	4.69 bc	8.11 bc	42.17 a
S_2Zn_2	23.14 ab	3.89 ab	5.33 ab	9.22 a	41.19 a
S_2Zn_3	23.51 a	4.00 a	5.36 a	9.36 a	42.74 a
Significance level	0.01	0.01	0.05	0.01	0.05
CV(%)	6.32	5.31	6.21	4.71	4.04

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

Different levels of zinc showed statistically significant variation for grain yield (Table 5). The highest grain yield (3.57 t ha^{-1}) was observed from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (3.37 t ha^{-1}) with Zn_2 (2.0 kg Zn ha^{-1}) and closely followed (3.08 t ha^{-1}) by Zn_1 (1.0 kg Zn ha^{-1}), whereas the lowest grain yield (2.35 t ha^{-1}) was observed from control (0 kg Zn ha^{-1}). Zinc deficiency is the most widespread micronutrient disorder in lowland rice and application of zinc along with NPK fertilizer increases the grain yield dramatically in most cases (Chaudhary *et al*., 2007; Muthukumararaja and Sriramachandrasekharan, 2012). Khan *et al*. (2007) reported that increasing levels of Zn significantly influenced grain yield of rice.

Grain yield ha^{-1} of BRRI dhan34 increased significantly due to interaction effect between sulphur and zinc (Table 6). The highest grain yield (4.00 t ha^{-1}) was recorded from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}) and the lowest grain yield (2.13 t ha^{-1}) was observed from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}). Hoque and Jahiruddin (1994) reported increased crop yields for S but not generally for Zn. Rahman *et al*. (2008) observed the highest grain (5.76 t ha^{-1}) from $S_{20}Zn_3$ treatment (100% recommended dose) and the lowest grain yield (4.35 t ha^{-1}) for control (S_0Zn_0).

4.1.11 Straw yield ha^{-1}

Statistically significant variation was recorded in terms of straw yield ha^{-1} due to different levels of sulphur (Table 5). The highest straw yield (4.83 t ha^{-1}) was observed from S_2 (12.0 kg S ha^{-1}), which was statistically identical (4.75 t ha^{-1}) with S_1 (8.0 kg S ha^{-1}), while the lowest straw yield (4.06 t ha^{-1}) was observed from S_0 (0 kg S ha^{-1}). Mrinal and Sharma (2008) reported that straw yield of rice increased significantly with increasing levels of sulphur up to 30 kg S ha^{-1}. Rahman *et al*. (2009) reported that straw yield of BRRI dhan41 significantly responded to different levels of S. Dixit *et al*. (2012) reported that application of 40 kg S ha^{-1} gave significantly higher straw yield.

Straw yield ha^{-1} showed statistically significant variation due to different levels of zinc (Table 5). The highest straw yield (4.91 t ha^{-1}) was recorded from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (4.80 t ha^{-1}) with Zn_2 (2.0 kg Zn ha^{-1}) and closely followed (4.47 t ha^{-1}) by Zn_1 (1.0 kg Zn ha^{-1}), whereas the lowest straw yield (4.01 t ha^{-1}) was obtained from Zn_0 i.e. 0 kg Zn ha^{-1}. Khan *et al*. (2007) reported that the increasing levels of Zn significantly influenced grain yield of rice.

Due to the interaction effect between sulphur and zinc the straw yield ha^{-1} of BRRI dhan34 increased significantly (Table 6). The highest straw yield (5.36 t ha^{-1}) was observed from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), while the lowest straw yield (3.88 t ha^{-1}) was found from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination. Rahman *et al*. (2008) recorded the highest straw (7.32 t ha^{-1}) yield with $S_{20}Zn_3$ treatment (100% recommended dose) and the S_0Zn_0 (control) had the lowest straw yield (5.47 t ha^{-1}).

4.1.12 Biological yield ha^{-1}

Biological yield ha^{-1} varied significantly for different levels of sulphur (Table 5). The highest biological yield (8.30 t ha^{-1}) was found from S_2 (12.0 kg S ha^{-1}), which was statistically identical (8.09 t ha^{-1}) with S_1 (8.0 kg S ha^{-1}), whereas the lowest biological yield (6.52 t ha^{-1}) wasrecorded from S_0 (0 kg S ha^{-1}). Rahman *et al*. (2009) reported that biological yield of BRRI dhan41 significantly responded increased for S application.

Statistically significant variation was recorded for biological yield ha^{-1} due to different levels of zinc (Table 5). The highest biological yield (8.48 t ha^{-1}) was observed from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (8.17 t ha^{-1}) with Zn_2 (2.0 kg Zn ha^{-1}) and closely followed (7.54 t ha^{-1}) by Zn_1 (1.0 kg Zn ha^{-1}). On the other hand, the lowest biological yield (6.37 t ha^{-1}) was found from Zn_0 i.e. 0 kg Zn ha^{-1}. Khan *et al*. (2007) reported that the increasing levels of Zn significantly influenced yield of rice.

Interaction effect of between sulphur and zinc showed significant variation on biological yield ha^{-1} of BRRI dhan34 (Table 6). The highest biological yield (9.36 t ha^{-1}) was recorded from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), whereas the lowest biological yield (6.01 t ha^{-1}) was observed from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}).

4.1.13 Harvest index

Different levels of sulphur showed statistically significant differences in terms of harvest index of BRRI dhan34 (Table 5). The highest harvest index (41.88%) was recorded from S_2 (12.0 kg S ha^{-1}), which was statistically identical (41.29%) with S_1 (8.0 kg S ha^{-1}), while the lowest harvest index (37.73%) was found from S_0 (0 kg S ha^{-1}). Singh and Singh (2014) reported that sulphur showed the positive response to harvest index while, it was negative under control condition.

Harvest index showed statistically significant variation due to different levels of zinc (Table 5). The highest harvest index (42.10%) was recorded from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (41.25% and 40.79%) with Zn_2 (2.0 kg Zn ha^{-1}) and Zn_1 (1.0 kg Zn ha^{-1}), again the lowest harvest index (36.95%) was obtained from Zn_0 i.e. 0 kg Zn ha^{-1}. Cheema *et al*. (2006) reported that harvest index showed positive correlation with the increase in $ZnSO_4$ levels from 2.5 to 10 kg ha^{-1}. *et al.* (2012) observed the highest harvest index with 4 kg Zn ha^{-1}.

Statistically significant variation was recorded due to the interaction effect interaction (sulphur × zinc) on harvest index of BRRI dhan34 (Table 6). The highest harvest index (42.74%) was observed from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), whereas the lowest harvest index (35.44%) was found from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}).

4.2 NPKSZn concentration in grain and straw

4.2.1 Grain

Statistically significant variation was recorded for NPKSZn concentration in grain due different levels of sulphur (Table 7). The maximum concentration in grain for N (0.647%), P (0.284%), K (0.356%), S (0.118%) and Zn (0.0139%) was observed from S_2 (12.0 kg S ha^{-1}), while the minimum concentration in grain for N (0.455%), P (0.216%), K (0.305%), S (0.109%) and Zn (0.0101%) was found from S_0 (0 kg S ha^{-1}).

NPKSZn concentration in grain showed statistically significant variation due to different levels of zinc (Table 7). The maximum concentration in grain for N (0.654%), P (0.283%), K (0.360%), S (0.120%) and Zn (0.0143%) was recorded from Zn_3 (3.0 kg Zn ha^{-1}) and the minimum concentration in grain for N (0.450%), P (0.214%), K (0.303%), S (0.106%) and Zn (0.0099%) was observed from Zn_0 i.e. 0 kg Zn ha^{-1}. Yadi *et al.* (2012) reported nitrogen phosphorus, potassium and sulphur content in grain was highest with 4 kg Zn ha^{-1}.

Interaction effect of sulphur and zinc showed statistically significant variation in terms of NPKSZn concentration in grain (Table 8). The maximum concentration in grain for N (0.767%), P (0.318%), K (0.396%), S (0.127%) and Zn (0.0164%) was observed from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), whereas the minimum concentration in grain for N (0.401%), P (0.194%), K (0.278%), S (0.101%) and Zn (0.0092%) was found from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

4.2.2 Straw

Different levels of sulphur showed statistically significant variation for NPKSZn concentration in straw (Table 9). Data revealed that the maximum concentration in straw for N (0.455%), P (0.071%), K (1.127%), S (0.082%) and Zn (0.0043%) was recorded from S_2 (12.0 kg S ha^{-1}), while the minimum concentration in straw for N (0.341%), P (0.047%), K (1.012%), S (0.068%) and Zn (0.0031%) was obtained from S_0 (0 kg S ha^{-1}).

Table 7. Effect of sulphur and zinc on N, P, K, S and Zn concentrations in grain of T. aman rice

Treatment	Concentration (%) in grain				
	N	P	K	S	Zn
Levels of sulphur					
S_0	0.455 c	0.216 c	0.305 b	0.109 b	0.0101 b
S_1	0.600 b	0.271 b	0.342 a	0.117 a	0.0132 a
S_2	0.647 a	0.284 a	0.356 a	0.118 a	0.0139 a
Significance level	0.01	0.01	0.01	0.01	0.01
Levels of zinc					
Zn_0	0.450 c	0.214 d	0.303 c	0.106 c	0.0099 b
Zn_1	0.550 b	0.257 c	0.327 bc	0.113 b	0.0121 ab
Zn_2	0.616 a	0.273 b	0.347 ab	0.119 a	0.0134a
Zn_3	0.654 a	0.283 a	0.360 a	0.120 a	0.0143 a
Significance level	0.01	0.01	0.01	0.01	0.01
CV(%)	7.45	6.24	8.38	6.22	6.62

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

Table 8. Interaction effect of sulphur and zinc on N, P, K, S and Zn concentrations in grain of T. aman rice

Treatment	Concentration (%) in grain				
	N	P	K	S	Zn
S_0Zn_0	0.401 h	0.194 h	0.278 d	0.101 e	0.0092 c
S_0Zn_1	0.446 gh	0.214 fg	0.295 cd	0.113 bc	0.0098 c
S_0Zn_2	0.431 gh	0.211 gh	0.325 bcd	0.106 d	0.0093 c
S_0Zn_3	0.544 ef	0.245 e	0.320 bcd	0.108 cd	0.0123 abc
S_1Zn_0	0.488 fg	0.230 ef	0.295 cd	0.107 cd	0.0103 abc
S_1Zn_1	0.587 de	0.269 d	0.339 abc	0.110 cd	0.0132 abc
S_1Zn_2	0.676 bc	0.297 bc	0.370 ab	0.124 a	0.0149 abc
S_1Zn_3	0.650 cd	0.287 c	0.365 ab	0.126 a	0.0142 abc
S_2Zn_0	0.462 gh	0.218 fg	0.289 cd	0.111 cd	0.0102 bc
S_2Zn_1	0.618 cde	0.288 c	0.348 abc	0.117 b	0.0132 abc
S_2Zn_2	0.742 ab	0.310 ab	0.392 a	0.126 a	0.0160 ab
S_2Zn_3	0.767 a	0.318 a	0.396 a	0.127 a	0.0164 a
Significance level	0.01	0.01	0.01	0.01	0.01
CV(%)	7.45	6.24	8.38	6.22	6.62

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

Table 9. Effect of sulphur and zinc on N, P, K, S and Zn concentrations in straw of T. aman rice

Treatment	Concentration (%) in straw				
	N	P	K	S	Zn
Levels of sulphur					
S_0	0.341 b	0.047 b	1.012 c	0.068 b	0.0031 b
S_1	0.440 a	0.068 a	1.108 b	0.078 a	0.0041 a
S_2	0.455 a	0.071 a	1.127 a	0.082 a	0.0043 a
Significance level	0.01	0.01	0.01	0.01	0.01
Levels of zinc					
Zn_0	0.332 c	0.045 c	1.024 d	0.066 c	0.0032 b
Zn_1	0.414 b	0.060 b	1.057 c	0.073 bc	0.0037 ab
Zn_2	0.438 ab	0.069 ab	1.112 b	0.081 ab	0.0041 ab
Zn_3	0.463 a	0.074 a	1.135 a	0.085 a	0.0044 a
Significance level	0.01	0.01	0.01	0.01	0.01
CV(%)	7.02	9.62	4.99	6.40	10.50

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

A statistically significant variation was recorded for NPKSZn concentration in straw due to different levels of zinc (Table 9). The maximum concentration in straw for N (0.463%), P (0.074%), K (1.135%), S (0.085%) and Zn (0.0044%) was found from Zn_3 (3.0 kg Zn ha^{-1}). On the other hand the minimum concentration in straw for N (0.332%), P (0.045%), K (1.024%), S (0.066%) and Zn (0.0032%) was observed from Zn_0 i.e. 0 kg Zn ha^{-1}.

NPKSZn concentration in straw showed statistically significant variation due to the interaction effect of sulphur and zinc (Table 10). The maximum concentration in straw for N (0.514%), P (0.087%), K (1.201%), S (0.094%) and Zn (0.0050%) was attained from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), again the minimum concentration in straw for N (0.310%), P (0.043%), K (0.983%), S (0.062%) and Zn (0.0026%) was recorded from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

4.3 NPKSZn uptake by grain and straw

4.3.1 Grain

Due to different levels of sulphur statistically significant variation was recorded for NPKSZn uptake by grain (Table 11). The maximum uptake by grain for N (29.70 kg ha^{-1}), P (12.94 kg ha^{-1}), K (16.21 kg ha^{-1}), S (5.35 kg ha^{-1}) and Zn (0.639 kg ha^{-1}) was found from S_2 (12.0 kg S ha^{-1}). On the other hand the minimum uptake by grain for N (15.88 kg ha^{-1}), P (7.52 kg ha^{-1}), K (10.53 kg ha^{-1}), S (3.78 kg ha^{-1}) and Zn (0.353 kg ha^{-1}) was attained from S_0 (0 kg S ha^{-1}). Vaiyapuri and Sriramachandrasekharan (2001) was noticed maximum nutrient uptake for N, P, K and S with 40 kg sulphur ha^{-1}.

Statistically significant differences was observed for NPKSZn uptake by grain due to different levels of zinc (Table 11). The maximum uptake by grain for N (30.32 kg ha^{-1}), P (13.10 kg ha^{-1}), K (16.62 kg ha^{-1}), S (5.54 kg ha^{-1}) and Zn (0.662 kg ha^{-1}) was observed from Zn_3 (3.0 kg Zn ha^{-1}), while the minimum uptake by grain for N (15.19 kg ha^{-1}), P (7.22 kg ha^{-1}), K (10.18 kg ha^{-1}), S (3.57 kg ha^{-1}) and Zn (0.333 kg ha^{-1}) was found from Zn_0 i.e. 0 kg Zn ha^{-1}.

Table 10. Interaction effect of sulphur and zinc on N, P, K, S and Zn concentrations in straw of T. aman rice

Treatment	Concentration (%) in straw				
	N	P	K	S	Zn
S_0Zn_0	0.310 d	0.043 d	0.983 g	0.062 c	0.0026 c
S_0Zn_1	0.332 d	0.045 d	1.000 g	0.066 bc	0.0029 bc
S_0Zn_2	0.317 d	0.046 d	0.988 g	0.067 bc	0.0032 abc
S_0Zn_3	0.405 c	0.054 cd	1.075 de	0.078 abc	0.0038 abc
S_1Zn_0	0.345 d	0.047 d	1.066 e	0.067 bc	0.0033 abc
S_1Zn_1	0.450 bc	0.066 bc	1.081 de	0.076 abc	0.0041 abc
S_1Zn_2	0.492 ab	0.080 ab	1.156 b	0.087 a	0.0047 ab
S_1Zn_3	0.471 ab	0.079 ab	1.129 c	0.082 ab	0.0043 abc
S_2Zn_0	0.341 d	0.046 d	1.024 f	0.064 bc	0.0031 abc
S_2Zn_1	0.459 abc	0.068 bc	1.091 d	0.077 abc	0.0042 abc
S_2Zn_2	0.504 ab	0.082 ab	1.191 a	0.093 a	0.0049 a
S_2Zn_3	0.514 a	0.087 a	1.201 a	0.094 a	0.0050 a
Significance level	0.01	0.01	0.01	0.01	0.01
CV(%)	7.02	9.62	4.99	6.40	10.50

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

Table 11. Effect of sulphur and zinc on N, P, K, S and Zn uptake by grain of T. aman rice

Treatment	Uptake by grain (kg ha^{-1})				
	N	P	K	S	Zn
Levels of sulphur					
S_0	15.88 c	7.52 c	10.53 b	3.78 b	0.353 c
S_1	26.49 b	11.91 b	15.07 a	5.12 a	0.582 b
S_2	29.70 a	12.94 a	16.21 a	5.35 a	0.639 a
Significance level	0.01	0.01	0.01	0.01	0.01
Levels of zinc					
Zn_0	15.19 d	7.22 c	10.18 c	3.57 c	0.333 d
Zn_1	22.87 c	10.66 b	13.50 b	4.64 b	0.502 c
Zn_2	27.72 b	12.18 a	15.44 a	5.25 a	0.602 b
Zn_3	30.32 a	13.10 a	16.62 a	5.54 a	0.662 a
Significance level	0.01	0.01	0.01	0.01	0.01
CV(%)	10.85	9.91	10.51	8.63	9.88

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

The uptake of NPKSZn by rice grain increased significantly due to interaction effect between sulphur and zinc (Table 12). The maximum uptake by grain for N (38.45 kg ha^{-1}), P (15.93 kg ha^{-1}), K (19.79 kg ha^{-1}), S (6.36 kg ha^{-1}) and Zn (0.819 kg ha^{-1}) was observed from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), whereas the minimum uptake by grain for N (12.55 kg ha^{-1}), P (6.08 kg ha^{-1}), K (9.85 kg ha^{-1}), S (3.48 kg ha^{-1}) and Zn (0.287 kg ha^{-1}) was found from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination. Dixit *et al*. (2012) reported that increasing doses of sulphur and zinc enhanced significantly their uptake by hybrid rice crop.

4.3.2 Straw

Statistically significant variation was recorded for NPKSZn uptake by straw due different levels of sulphur (Table 13). The maximum uptake by straw for N (26.90 kg ha^{-1}), P (4.22 kg ha^{-1}), K (66.08 kg ha^{-1}), S (4.85 kg ha^{-1}) and Zn (0.256 kg ha^{-1}) was obtained from S_2 (12.0 kg S ha^{-1}). The minimum uptake by straw for N (17.32 kg ha^{-1}), P (2.38 kg ha^{-1}), K (51.29 kg ha^{-1}), S (3.47 kg ha^{-1}) and Zn (0.160 kg ha^{-1}) was found from S_0 (0 kg S ha^{-1}).

Different levels of zinc showed statistically significant variation for NPKSZn uptake by straw (Table 13). The maximum uptake by straw for N (27.58 kg ha^{-1}), P (4.41 kg ha^{-1}), K (67.30 kg ha^{-1}), S (5.02 kg ha^{-1}) and Zn (0.261 kg ha^{-1}) was found from Zn_3 (3.0 kg Zn ha^{-1}), while the minimum uptake by straw for N (16.72 kg ha^{-1}), P (2.29 kg ha^{-1}), K (51.39 kg ha^{-1}), S (3.34 kg ha^{-1}) and Zn (0.163 kg ha^{-1}) was observed from Zn_0 i.e. 0 kg Zn ha^{-1}.

Significant variation was observed for NPKSZn uptake by straw due to the interaction effect between sulphur and zinc (Table 14). The maximum uptake by straw for N (32.69 kg ha^{-1}), P (5.56 kg ha^{-1}), K (76.44 kg ha^{-1}), S (5.95 kg ha^{-1}) and Zn (0.319 kg ha^{-1}) was recorded from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}). On the other hand, the minimum uptake by straw for N (15.82 kg ha^{-1}), P (2.19 kg ha^{-1}), K (50.05 kg ha^{-1}), S (3.08 kg ha^{-1}) and Zn (0.128 kg ha^{-1}) was obtained from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

Table 12. Interaction effect of sulphur and zinc on N, P, K, S and Zn uptake by grain of T. aman rice

Treatment	Uptake by grain (kg ha^{-1})				
	N	P	K	S	Zn
S_0Zn_0	12.55 e	6.08 f	9.85 d	3.48 d	0.287 e
S_0Zn_1	14.68 e	7.05 f	9.72 d	3.72 d	0.322 e
S_0Zn_2	15.30 e	7.48 f	10.20 d	3.78 d	0.329 e
S_0Zn_3	20.99 d	9.45 e	12.34 d	4.16 d	0.474 d
S_1Zn_0	16.87 de	7.94 ef	10.25 d	3.70 d	0.355 e
S_1Zn_1	25.98 c	11.88 d	15.01 c	4.87 c	0.585 c
S_1Zn_2	31.59 b	13.89 bc	17.30 abc	5.79 ab	0.696 b
S_1Zn_3	31.53 b	13.94 bc	17.73 ab	6.11 a	0.692 b
S_2Zn_0	16.16 e	7.63 ef	10.10 d	3.53 d	0.356 e
S_2Zn_1	27.95 bc	13.05 cd	15.76 bc	5.32 bc	0.598 c
S_2Zn_2	36.26 a	15.16 ab	19.17 a	6.18 a	0.781 ab
S_2Zn_3	38.45 a	15.93 a	19.79 a	6.36 a	0.819 a
Significance level	0.01	0.01	0.01	0.01	0.01
CV(%)	10.85	9.91	10.51	8.63	9.88

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

S_0: 0 kg S ha^{-1} (control)
S_1: 8.0 kg S ha^{-1}
S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)
Zn_1: 1.0 kg Zn ha^{-1}
Zn_2: 2.0 kg Zn ha^{-1}
Zn_3: 3.0 kg Zn ha^{-1}

Table 13. Effect of sulphur and zinc on N, P, K, S and Zn uptake by straw of T. aman rice

Treatment	Uptake by straw (kg ha^{-1})				
	N	P	K	S	Zn
Levels of sulphur					
S_0	17.32 b	2.38 b	51.29 b	3.47 b	0.160 b
S_1	25.54 a	3.98 a	63.83 a	4.52 a	0.239 a
S_2	26.90 a	4.22 a	66.08 a	4.85 a	0.256 a
Significance level	0.01	0.01	0.01	0.01	0.01
Levels of zinc					
Zn_0	16.72 c	2.29 c	51.39 c	3.34 c	0.163 c
Zn_1	22.80 b	3.30 b	57.92 b	4.00 b	0.206 b
Zn_2	25.91 a	4.12 a	65.00 a	4.75 a	0.243 a
Zn_3	27.58 a	4.41 a	67.30 a	5.02 a	0.261 a
Significance level	0.01	0.01	0.01	0.01	0.01
CV(%)	9.15	12.63	6.68	10.57	13.46

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

S_0: 0 kg S ha^{-1} (control)
S_1: 8.0 kg S ha^{-1}
S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)
Zn_1: 1.0 kg Zn ha^{-1}
Zn_2: 2.0 kg Zn ha^{-1}
Zn_3: 3.0 kg Zn ha^{-1}

Table 14. Interaction effect of sulphur and zinc on N, P, K, S and Zn uptake by straw of T. aman rice

Treatment	Uptake by straw (kg ha^{-1})				
	N	P	K	S	Zn
S_0Zn_0	15.82 d	2.19 c	50.05 c	3.08 f	0.128 e
S_0Zn_1	16.52 d	2.23 c	49.82 c	3.27 ef	0.144 de
S_0Zn_2	15.77 d	2.28 c	49.08 c	3.43 ef	0.168 de
S_0Zn_3	21.18 c	2.82 c	56.22 bc	4.09 de	0.201 cd
S_1Zn_0	17.49 d	2.40 c	53.70 c	3.40 ef	0.169 de
S_1Zn_1	25.76 b	3.80 b	61.87 b	4.34 cd	0.236 bc
S_1Zn_2	30.04 a	4.89 a	70.51 a	5.30 ab	0.288 ab
S_1Zn_3	28.86 ab	4.85 a	69.25 a	5.02 bc	0.263 ab
S_2Zn_0	16.86 d	2.27 c	50.43 c	3.18 f	0.154 de
S_2Zn_1	26.12 b	3.86 b	62.07 b	4.39 cd	0.239 bc
S_2Zn_2	31.94 a	5.18 a	75.40 a	5.87 a	0.313 a
S_2Zn_3	32.69 a	5.56 a	76.44 a	5.95 a	0.319 a
Significance level	0.01	0.01	0.01	0.01	0.01
CV(%)	9.15	12.63	6.68	10.57	13.46

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

4.4 pH, organic matter, S and Zn in post harvest soil

4.4.1 pH

Different levels of sulphur varied non significantly in terms of pH in post harvest soil (Table 15). The highest pH in post harvest soil (6.24) was observed from S_2 (12.0 kg S ha^{-1}), while the lowest pH (6.14) was found from S_0 (0 kg S ha^{-1}).

Statistically non significant variation was recorded for pH in post harvest soil due to different levels of zinc (Table 15). The highest pH in post harvest soil (6.27) was recorded from Zn_3 (3.0 kg Zn ha^{-1}), whereas the lowest pH (6.11) from Zn_0 i.e. 0 kg Zn ha^{-1}.

Interaction effect of different levels of sulphur and zinc showed non significant variation on pH in post harvest soil (Table 16). The highest pH in post harvest soil (6.33) was observed from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}) and the lowest pH in post harvest soil (6.06) was found from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

4.4.2 Organic matter

Organic matter in post harvest soil varied non significantly for different levels of sulphur (Table 15). The highest organic matter in post harvest soil (1.34%) was found from S_2 (12.0 kg S ha^{-1}), whereas the lowest organic matter in post harvest soil (1.21%) was recorded from S_0 (0 kg S ha^{-1}).

Different levels of zinc showed statistically non significant differences for organic matter in post harvest soil due to (Table 15). Data revealed that the highest organic matter in post harvest soil (1.32%) was observed from Zn_3 (3.0 kg Zn ha^{-1}), while the lowest organic matter in post harvest soil (1.24%) from Zn_0 i.e. 0 kg Zn ha^{-1}.

Table 15. Effect of sulphur and zinc on the nutrient content of post harvest soil

Treatment	pH	Organic matter (%)	Available S (ppm)	Available Zn (ppm)
Levels of sulphur				
S_0	6.14	1.21	8.00 c	0.328 c
S_1	6.21	1.30	11.33 b	0.595 b
S_2	6.24	1.34	13.83 a	0.622 a
Significance level			0.01	0.01
Levels of zinc				
Zn_0	6.11	1.24	10.35 b	0.327 d
Zn_1	6.16	1.28	11.17 ab	0.516 c
Zn_2	6.24	1.30	11.12 ab	0.566 b
Zn_3	6.27	1.32	11.58 a	0.651 a
Significance level	NS	NS	0.01	0.01
CV(%)	4.67	6.02	7.64	5.43

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

Table 16. Interaction effect of sulphur and zinc on the nutrient content of post harvest soil

Treatment	pH	Organic matter (%)	Available S (ppm)	Available Zn (ppm)
S_0Zn_0	6.06	1.14	7.26 e	0.267 h
S_0Zn_1	6.13	1.20	7.45 e	0.290 gh
S_0Zn_2	6.17	1.24	7.88 e	0.327 fg
S_0Zn_3	6.19	1.26	9.43 d	0.430 e
S_1Zn_0	6.11	1.25	10.27 d	0.337 fg
S_1Zn_1	6.15	1.31	12.27 bc	0.623 d
S_1Zn_2	6.28	1.30	11.86 bc	0.670 cd
S_1Zn_3	6.30	1.34	10.93 cd	0.749 ab
S_2Zn_0	6.16	1.32	12.90 ab	0.377 ef
S_2Zn_1	6.19	1.32	13.81 a	0.637d
S_2Zn_2	6.26	1.35	14.24 a	0.700 bc
S_2Zn_3	6.33	1.36	14.37 a	0.773 a
Significance level	NS	NS	0.01	0.01
CV(%)	4.67	6.02	7.64	5.43

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

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

S_1: 8.0 kg S ha^{-1}

S_2: 12.0 kg S ha^{-1}

Zn_0: 0 kg Zn ha^{-1} (control)

Zn_1: 1.0 kg Zn ha^{-1}

Zn_2: 2.0 kg Zn ha^{-1}

Zn_3: 3.0 kg Zn ha^{-1}

Statistically non significant variation was recorded due to the interaction effect of different levels of sulphur and zinc in terms of organic matter in post harvest soil (Table 16). The highest organic matter in post harvest soil (1.36%) was found from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), while the lowest organic matter in post harvest soil (1.14%) was recorded from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

4.4.3 Available sulphur

Available sulphur in post harvest soil varied significantly for different levels of sulphur (Table 15). The highest available sulphur in post harvest soil (13.83 ppm) was recorded from S_2 (12.0 kg S ha^{-1}), which was closely followed (11.33 ppm) by S_1 (8.0 kg S ha^{-1}), whereas the lowest available sulphur in post harvest soil (8.00 ppm) was found from S_0 (0 kg S ha^{-1}). Peng *et al.* (2002) reported that the average content of available S in these soil samples was 21.7 mg kg^{-1} by applying S at the doses of 20-60 kg ha^{-1} to rice plant.

Statistically significant variation was recorded for available sulphur in post harvest soil due to different levels of zinc (Table 15). The highest available sulphur in post harvest soil (11.58 ppm) was observed from Zn_3 (3.0 kg Zn ha^{-1}) which was statistically similar (11.12 ppm and 11.17 ppm) with Zn_2 (2.0 kg Zn ha^{-1}) and Zn_1 (1.0 kg Zn ha^{-1}) and the lowest available sulphur in post harvest soil (10.35 ppm) was obtained from Zn_0 i.e. 0 kg Zn ha^{-1}.

Interaction effect of different levels of sulphur and zinc showed significant variation on available sulphur in post harvest soil (Table 16). The highest available sulphur in post harvest soil (14.37 ppm) was found from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}). On the other hand, the lowest available sulphur in post harvest soil (7.26 ppm) was recorded from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}).

4.4.4 Available zinc

Different levels of sulphur varied significantly in terms of available zinc in post harvest soil (Table 15). The highest available zinc in post harvest soil (0.622 ppm) was observed from S_2 (12.0 kg S ha^{-1}), which was closely followed (0.595 ppm) by S_1 (8.0 kg S ha^{-1}), while the lowest available zinc in post harvest soil (0.328 ppm) was recorded from S_0 (0 kg S ha^{-1}).

Available zinc in post harvest soil showed statistically significant variation due to different levels of zinc (Table 15). The highest available zinc in post harvest soil (0.651 ppm) was recorded from Zn_3 (3.0 kg Zn ha^{-1}), which was closely followed (0.566 ppm) by Zn_2 (2.0 kg Zn ha^{-1}). On the other hand the lowest available zinc in post harvest soil (0.327 ppm) from control (0 kg Zn ha^{-1}) which was followed (0.516 ppm) by Zn_1 (1.0 kg Zn ha^{-1}).

Statistically significant variation was recorded due to the interaction effect of different levels of sulphur and zinc in terms of available zinc in post harvest soil (Table 16). The highest available zinc in post harvest soil (0.773 ppm) was observed from S_2Zn_3 (12.0 kg S ha^{-1} and 3.0 kg Zn ha^{-1}), whereas the lowest available zinc in post harvest soil (0.267 ppm) was found from S_0Zn_0 (0 kg S ha^{-1} and 0 kg Zn ha^{-1}) treatment combination.

CHAPTER V

SUMMARY AND CONCLUSION

In case of sulphur fertilizer, at 30, 45, 60, 75 DAT and harvest, the tallest plant (23.93, 50.99, 79.40, 92.46 and 115.27 cm, respectively) was observed from S_2, whereas the shortest plant (18.62, 46.86, 69.04, 86.63 and 106.60 cm, respectively) from S_0. The maximum number of effective tillers hill^{-1} (15.07) was recorded from S_2, while the minimum number (11.87) from S_0. The maximum number of non-effective tillers hill^{-1} (3.37) was found from S_2 and the minimum number (2.50) from S_0. The maximum number of total tillers hill^{-1} (18.43) was observed from S_2, while the minimum number (14.37) from S_0. The longest panicle (25.81 cm) was recorded from S_2, whereas the shortest panicle (22.29 cm) from S_0. The highest weight of 1000-grains (21.58 g) was found from S_2, while the lowest weight (19.65 g) from S_0. The maximum number of filled grains panicle^{-1} (83.90) was found from S_2, whereas the minimum (71.72) from S_0. The maximum number of unfilled grains panicle^{-1} (7.97) was observed from S_2 and the minimum (6.42) from S_0. The maximum number of total grains panicle^{-1} (91.87) was recorded from S_2, while the minimum (78.13) from S_0. The highest grain yield (3.48 t ha^{-1}) was found from S_2 (12.0 kg S ha^{-1}), again the lowest (2.46 t ha^{-1}) from S_0. The highest straw yield (4.83 t ha^{-1}) was observed from S_2, while the lowest (4.06 t ha^{-1}) from S_0. The highest biological yield (8.30 t ha^{-1}) was found from S_2, whereas the lowest (6.52 t ha^{-1}) from S_0. The highest harvest index (41.88%) was recorded from S_2, while the lowest (37.73%) from S_0.

The maximum concentration in grain for N (0.647%), P (0.284%), K (0.356%), S (0.118%) and Zn (0.0139%) was observed from S_2, while the minimum concentration in grain for N (0.455%), P (0.216%), K (0.305%), S (0.109%) and Zn (0.0101%) from S_0. The maximum concentration in straw for N (0.455%), P (0.071%), K (1.127%), S (0.082%) and Zn (0.0043%) was recorded from S_2, while the minimum concentration in straw for N (0.341%), P (0.047%), K (1.012%), S (0.068%) and Zn (0.0031%) from S_0. The maximum uptake by grain for N (29.70 kg ha^{-1}), P (12.94 kg ha^{-1}), K (16.21 kg ha^{-1}), S (5.35 kg ha^{-1}) and Zn (0.639 kg ha^{-1}) was found from S_2 and the minimum uptake by grain for N (15.88 kg ha^{-1}), P (7.52 kg ha^{-1}), K (10.53 kg ha^{-1}), S (3.78 kg ha^{-1}) and Zn (0.353 kg ha^{-1}) from S_0. The maximum uptake by straw for N (26.90 kg ha^{-1}), P (4.22 kg ha^{-1}), K (66.08 kg ha^{-1}), S (4.85 kg ha^{-1}) and Zn (0.256 kg ha^{-1}) was obtained from S_2, again the minimum uptake by straw for N (17.32 kg ha^{-1}), P (2.38 kg ha^{-1}), K (51.29 kg ha^{-1}), S (3.47 kg ha^{-1}) and Zn (0.160 kg ha^{-1}) from S_0. The highest pH in post harvest soil (6.24) was observed from S_2, while the lowest (6.14) from S_0. The highest organic matter in post harvest soil (1.34%) was found from S_2, whereas the lowest (1.21%) from S_0. The highest available sulphur in post harvest soil (13.83 ppm) was recorded from S_2, whereas the lowest (8.00 ppm) from S_0. The highest available zinc in post harvest soil (0.622 ppm) was observed from S_2, while the lowest (0.328 ppm) from S_0.

For different levels of zinc at 30, 45, 60, 75 DAT and harvest, the tallest plant (23.92, 52.24, 80.23, 93.78 and 116.73 cm, respectively) was recorded from Zn_3, while the shortest plant (18.46, 45.97, 68.79, 84.71 and 106.59 cm, respectively) from Zn_0. The maximum number of effective tillers $hill^{-1}$ (15.31) was obtained from Zn_3 but the minimum (11.61) from Zn_0. The maximum number of non-effective tillers $hill^{-1}$ (3.47) was attained from Zn_3, whereas the minimum (2.33) from Zn_0. The maximum number of total tillers $hill^{-1}$ (18.78) was found from Zn_3, again the minimum (13.94) from Zn_0. The longest panicle (27.08 cm) was attained from Zn_3, while the shortest panicle (20.80 cm) from Zn_0. The highest weight of 1000-grains (21.93 g) was recorded from Zn_3 and the lowest weight (19.22 g) from Zn_0. The maximum number of filled grains $panicle^{-1}$ (84.71) was observed from Zn_3, while the minimum (72.62) from Zn_0. The maximum number of unfilled grains $panicle^{-1}$ (8.16) was recorded from Zn_3, while the minimum (6.51) from Zn_0. The maximum number of total grains $panicle^{-1}$ (92.87) was observed from Zn_3, again the minimum (79.13) from Zn_0. The highest grain yield (3.57 t ha^{-1}) was observed from Zn_3, whereas the lowest (2.35 t ha^{-1}) from Zn_0. The highest straw yield (4.91 t ha^{-1}) was recorded from Zn_3, whereas the lowest (4.01 t ha^{-1})

from Zn_0. The highest biological yield (8.48 t ha^{-1}) was observed from Zn_3 and the lowest (6.37 t ha^{-1}) from Zn_0. The highest harvest index (42.10%) was recorded from Zn_3, again the lowest (36.95%) from Zn_0.

The maximum concentration in grain for N (0.654%), P (0.283%), K (0.360%), S (0.120%) and Zn (0.0143%) was recorded from Zn_3 and the minimum concentration in grain for N (0.450%), P (0.214%), K (0.303%), S (0.106%) and Zn (0.0099%) from Zn_0. The maximum concentration in straw for N (0.463%), P (0.074%), K (1.135%), S (0.085%) and Zn (0.0044%) was found from Zn_3 and the minimum concentration in straw for N (0.332%), P (0.045%), K (1.024%), S (0.066%) and Zn (0.0032%) from Zn_0. The maximum uptake by grain for N (30.32 kg ha^{-1}), P (13.10 kg ha^{-1}), K (16.62 kg ha^{-1}), S (5.54 kg ha^{-1}) and Zn (0.662 kg ha^{-1}) was observed from Zn_3, while the minimum uptake by grain for N (15.19 kg ha^{-1}), P (7.22 kg ha^{-1}), K (10.18 kg ha^{-1}), S (3.57 kg ha^{-1}) and Zn (0.333 kg ha^{-1}) from Zn_0. The maximum uptake by straw for N (27.58 kg ha^{-1}), P (4.41 kg ha^{-1}), K (67.30 kg ha^{-1}), S (5.02 kg ha^{-1}) and Zn (0.261 kg ha^{-1}) was found from Zn_3, while the minimum uptake by straw for N (16.72 kg ha^{-1}), P (2.29 kg ha^{-1}), K (51.39 kg ha^{-1}), S (3.34 kg ha^{-1}) and Zn (0.163 kg ha^{-1}) from Zn_0. The highest pH in post harvest soil (6.27) was recorded from Zn_3, whereas the lowest (6.11) from Zn_0. The highest organic matter in post harvest soil (1.32%) was observed from Zn_3, while the lowest (1.24%) from Zn_0. The highest available sulphur in post harvest soil (11.58 ppm) was observed from Zn_3 and the lowest (10.35 ppm) from Zn_0. The highest available zinc in post harvest soil (0.651 ppm) was recorded from Zn_3 (3.0 kg Zn ha^{-1}) and the lowest (0.327 ppm) from Zn_0.

Due to the interaction effect of different levels of sulphur and zinc, at 30, 45, 60, 75 DAT and harvest, the tallest plant (26.65, 54.48, 87.32, 98.67 and 122.53 cm, respectively) from S_2Zn_3 and the shortest plant (16.89, 45.09, 63.66, 81.05 and 103.81 cm) from S_0Zn_0 treatment combination. The maximum number of effective tillers $hill^{-1}$ (16.73) was recorded from S_2Zn_3, whereas the minimum (11.00) from S_0Zn_0. The maximum number of non-effective tillers $hill^{-1}$ (3.87) was recorded from S_2Zn_3, while the minimum (2.13) from S_0Zn_0. The maximum number of total tillers hill^{-1} (20.60) was observed from S_2Zn_3 but the minimum number (13.13) from S_0Zn_0. The longest panicle (29.65 cm) was obtained from S_2Zn_3, again the shortest panicle (20.23 cm) from S_0Zn_0. The highest weight of 1000-grains (23.51 g) was recorded from S_2Zn_3, whereas the lowest weight (18.16 g) from S_0Zn_0. The maximum number of filled grains panicle^{-1} (90.53) was recorded from S_2Zn_3 and the minimum (65.27) from S_0Zn_0. The maximum number of unfilled grains panicle^{-1} (9.13) was observed from S_2Zn_3, again the minimum (5.87) from S_0Zn_0. The maximum number of total grains panicle^{-1} (99.67) was obtained from S_2Zn_3, whereas the minimum (71.13) from S_0Zn_0. The highest grain yield (4.00 t ha^{-1}) was recorded from S_2Zn_3 and the lowest (2.13 t ha^{-1}) from S_0Zn_0. The highest straw yield (5.36 t ha^{-1}) was observed from S_2Zn_3, while the lowest (3.88 t ha^{-1}) from S_0Zn_0. The highest biological yield (9.36 t ha^{-1}) was recorded from S_2Zn_3, whereas the lowest (6.01 t ha^{-1}) from S_0Zn_0. The highest harvest index (42.74%) was observed from S_2Zn_3, whereas the lowest (35.44%) from S_0Zn_0.

The maximum concentration in grain for N (0.767%), P (0.318%), K (0.396%), S (0.127%) and Zn (0.0164%) was observed from S_2Zn_3, whereas the minimum concentration in grain for N (0.401%), P (0.194%), K (0.278%), S (0.101%) and Zn (0.0092%) from S_0Zn_0. The maximum concentration in straw for N (0.514%), P (0.087%), K (1.201%), S (0.094%) and Zn (0.0050%) was attained from S_2Zn_3, again the minimum concentration in straw for N (0.310%), P (0.043%), K (0.983%), S (0.062%) and Zn (0.0026%) from S_0Zn_0. The maximum uptake by grain for N (38.45 kg ha^{-1}), P (15.93 kg ha^{-1}), K (19.79 kg ha^{-1}), S (6.36 kg ha^{-1}) and Zn (0.819 kg ha^{-1}) was observed from S_2Zn_3, whereas the minimum uptake by grain for N (12.55 kg ha^{-1}), P (6.08 kg ha^{-1}), K (9.85 kg ha^{-1}), S (3.48 kg ha^{-1}) and Zn (0.287 kg ha^{-1}) from S_0Zn_0. The maximum uptake by straw for N (32.69 kg ha^{-1}), P (5.56 kg ha^{-1}), K (76.44 kg ha^{-1}), S (5.95 kg ha^{-1}) and Zn (0.319 kg ha^{-1}) was recorded from S_2Zn_3 and the minimum uptake by straw for N (15.82 kg ha^{-1}), P (2.19 kg ha^{-1}), K (50.05 kg ha^{-1}), S (3.08 kg ha^{-1}) and Zn (0.128 kg ha^{-1}) was obtained from S_0Zn_0. The highest pH in post harvest soil (6.33) was observed from S_2Zn_3 and the lowest (6.06) from S_0Zn_0. The highest organic matter in post harvest soil (1.36%) was found from S_2Zn_3, while the lowest (1.14%) from S_0Zn_0. The highest available sulphur in post harvest soil (14.37 ppm) was found from S_2Zn_3, again the lowest (7.26 ppm) from S_0Zn_0. The highest available zinc in post harvest soil (0.773 ppm) was observed from S_2Zn_3, whereas the lowest (0.267 ppm) from S_0Zn_0.

Conclusion

- T. aman rice responded significantly sulphur and zinc application
- Sulphur @ 8.0 kg S ha^{-1} and zinc @ 2.0 kg Zn ha^{-1} as the best suited combination for maximizing the yield of rice in the study area.

Recommendation

Therefore, a package of 8.0 kg S ha^{-1} along with 2.0 kg Zn ha^{-1} may be recommended for T. aman cultivation in Shallow Red Brown Terrace Soil under Madhupur Tract (AEZ-28) of Dhaka district.

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APPENDICES

Appendix I. Monthly record of air temperature, relative humidity, rainfall, and sunshine (average) of the experimental site during the period from June to Novenber 2013

Month (2013)	Air temperature (^{0}c)		Relative humidity (%)	Rainfall (mm)	Sunshine (hr)
	Maximum	Minimum			
June	35.4	22.5	80	577	4.2
July	36.0	24.6	83	563	3.1
August	36.0	23.6	81	319	4.0
September	34.8	24.4	81	279	4.4
October	26.5	19.4	81	22	6.9
November	25.8	16.0	78	00	6.8

Source: Bangladesh Meteorological Department (Climate & weather division) Agargoan, Dhaka–1212*

Appendix II. Characteristics of experimental field soil as analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Exprimental field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% clay	30
Textural class	Silty-clay
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	1.12
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Source: SRDI

Appendix III. Analysis of variance of the data on plant height of T. aman rice as influenced by different levels of sulphur and zinc

Source of variation	Degrees of freedom	Mean square				
		Plant height (cm) at				
		30 DAT	45 DAT	60 DAT	75 DAT	Harvest
Replication	2	0.944	5.670	11.712	8.768	1.135
Level of sulphur (A)	2	95.284**	53.938**	345.465**	120.977**	235.530**
Level of Zinc (B)	3	51.823**	69.429**	221.613**	155.988**	193.382**
Interaction (A×B)	6	5.617**	15.125*	138.546**	88.034**	42.992*
Error	22	1.587	5.488	31.500	23.617	14.522

**: Significant at 0.01 level of probability: *: Significant at 0.05 level of probability

Appendix IV. Analysis of variance of the data on effective, non-effective & total tillers hill^{-1}, panicle length and filled, unfilled and total grains panicle^{-1} of T. aman rice as influenced by different levels of sulphur and zinc

Source of variation	Degrees of freedom	Mean square						
		Number of effective tiller hill^{-1}	Number of non-effective tiller hill^{-1}	Total tiller hill^{-1}	Length of panicle (cm)	Number of filled grain plant^{-1}	Number of unfilled grain plant^{-1}	Total grain plant^{-1}
Replication	2	0.008	0.023	0.026	0.749	4.243	0.103	5.452
Level of sulphur (A)	2	36.242**	2.743**	58.916**	37.813**	511.723**	8.768**	654.160**
Level of Zinc (B)	3	23.140**	2.437**	40.414**	70.903**	235.118**	4.350**	303.429**
Interaction (A×B)	6	3.311**	0.130*	4.543**	14.654**	112.486**	1.537**	137.906**
Error	22	0.590	0.044	0.804	2.475	20.887	0.352	24.724

**: Significant at 0.01 level of probability: *: Significant at 0.05 level of probability

Appendix V. Analysis of variance of the data on 1000 grains, grain, straw & biological yield and harvest index of T. aman rice as influenced by different levels of sulphur and zinc

Source of variation	Degrees of freedom	Mean square				
		Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	1.444	0.003	0.014	0.026	0.104
Level of sulphur (A)	2	11.162**	3.670**	2.113**	11.352**	25.880**
Level of Zinc (B)	3	12.346**	2.553**	1.455**	7.834**	19.802**
Interaction (A×B)	6	5.646*	0.178**	0.368*	1.021**	6.414*
Error	22	1.697	0.047	0.119	0.206	2.919

**: Significant at 0.01 level of probability: *: Significant at 0.05 level of probability

Appendix VI. Analysis of variance of the data on N, P, K, S and Zn concentrations in grain of T. aman rice as influenced by different levels of sulphur and zinc

Source of variation	Degrees of freedom	Mean square				
		Concentration (%) in grain				
		N	P	K	S	Zn
Replication	2	0.001	0.000	0.000	0.0001	0.0001
Level of sulphur (A)	2	0.120**	0.015**	0.009**	0.0001**	0.0001**
Level of Zinc (B)	3	0.072**	0.008**	0.006**	0.0001**	0.0001**
Interaction (A×B)	6	0.010**	0.001**	0.003**	0.0001**	0.0001**
Error	22	0.002	0.000	0.001	0.00001	0.00001

**: Significant at 0.01 level of probability:

Appendix VII. Analysis of variance of the data on N, P, K, S and Zn concentrations in straw of T. aman rice as influenced by different levels of sulphur and zinc

Source of variation	Degrees of freedom	Mean square				
		Concentration (%) in straw				
		N	P	K	S	Zn
Replication	2	0.0001	0.0001	0.0001	0.0001	0.0001
Level of sulphur (A)	2	0.046**	0.002**	0.046**	0.001**	0.0001**
Level of Zinc (B)	3	0.029**	0.001**	0.023**	0.001**	0.0001**
Interaction (A×B)	6	0.004**	0.000**	0.005**	0.0001**	0.0001**
Error	22	0.001	0.000	0.000	0.00001	0.00001

**: Significant at 0.01 level of probability:

Appendix VIII. Analysis of variance of the data on N, P, K, S and Zn uptake by grain of T. aman rice as influenced by different levels of sulphur and zinc

Source of variation	Degrees of freedom	Mean square				
		Uptake by grain (kg ha^{-1})				
		N	P	K	S	Zn
Replication	2	0.532	0.132	0.521	0.029	0.000
Level of sulphur (A)	2	628.300**	99.616**	108.302**	8.559**	0.275**
Level of Zinc (B)	3	397.916**	60.208**	71.278**	6.847**	0.186**
Interaction (A×B)	6	45.644**	5.833**	13.822**	0.953**	0.023**
Error	22	6.790	1.143	2.145	0.168	0.003

**: Significant at 0.01 level of probability:

Appendix IX. Analysis of variance of the data on N, P, K, S and Zn uptake by straw of T. aman rice as influenced by different levels of sulphur and zinc

Source of variation	Degrees of freedom	Mean square				
		Uptake by straw (kg ha^{-1})				
		N	P	K	S	Zn
Replication	2	0.483	0.073	3.623	0.021	0.000
Level of sulphur (A)	2	322.347**	12.005**	762.260**	6.241**	0.031**
Level of Zinc (B)	3	205.875**	8.165**	468.213**	5.214**	0.017**
Interaction (A×B)	6	35.426**	1.433**	100.186**	1.392**	0.006**
Error	22	4.527	0.199	16.283	0.204	0.001

**: Significant at 0.01 level of probability:

Appendix X. Analysis of variance of the data on post harvest soil of T. aman rice as influenced by different levels of sulphur and zinc

Source of variation	Degrees of freedom	Mean square			
		Status of nutrient in post harvest soil			
		pH	Organic matter (%)	Available S (ppm)	Available Zn (ppm)
Replication	2	0.029	0.003	0.077	0.0001
Level of sulphur (A)	2	0.689	0.078	102.455**	0.315**
Level of Zinc (B)	3	0.545	0.067	2.361*	0.169**
Interaction (A×B)	6	0.729	0.023	2.157*	0.016**
Error	22	0.886	0.073	0.714	0.001

**: Significant at 0.01 level of probability: *: Significant at 0.05 level of probability