EFFECTS OF SULPHUR AND ZINC ON THE YIELD OF T-AMAN RICE (BRRI Dhan-31)

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This is to certify that the thesis titled, *"EFFECT OF SULPHUR AND ZINC ON THE YIELD OF T-AMAN (BRRI DHAN 31)* submitted to the ***DEPARTMENT OF SOIL SCIENCE***, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka in partial fulfillment of the requirements for the degree of ***MASTER OF SCIENCE (M.S.)*** in ***SOIL SCIENCE*** embodies the result of a piece of *bona fide* research work carried out by ***KAZI MOSHIUR RAHMAN***, Registration No. ***00705*** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

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DADICATED

TO

ALL MY RESPECTED TEACHERS OF SOIL SCIENCE DEPARTMT

(S.A.U)

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ABSTRACT

A field experiment was conducted at Sher-e-Bangla Agricultural University farm, Dhaka from July to October 2007 with an objective of evaluating the effect of S and Zn on the yield ,yield components and nutrient uptake by T-Aman (BRRI dhan31).The soil was silt loam having pH 5.7, 1.18% organic matter, 16 ppm available S and 0.8 ppm available Zn contents. There were twelve treatments taking various doses of Sulphur and Zinc viz. S_0Zn_0 (control), S_0Zn_1, S_0Zn_2, $S_{12}Zn_0$, $S_{12}Zn_1$, $S_{12}Zn_2$, $S_{16}Zn_0$, $S_{16}Zn_1$, $S_{16}Zn_2$, $S_{20}Zn_0$, $S_{20}Zn_1$, $S_{20}Zn_2$. The subscripts represent doses in Kg/ha. The treatments were laid out in a randomized block design with three replications. All plots received recommended doses of N, P, and K to support normal plant growth. N, P, K, S, and Zn were applied in the form of Urea, T.S.P, MOP, Gypsum, and ZnSO4 respectively. The application of Sulphur and Zinc had a positive significant effect on tillers/hill, plant height, panicle length and no. of grains/panicle. The highest grain yield (4.20 t/ha) and straw yield (5.62 t/ha) of BRRI dhan 31 was recorded in $S_{20}Z_{n2}$ treatment. The S_0Z_{n0} treatment (control) had the lowest grain (3.01 t/ha) and straw yield (4.50 t/ha). The application of Sulphur and Zn fertilizers significantly increased the S and Zn contents as well as their uptake by rice crop. Over all results indicate that the application of Sulphur and Zn at a rate of 20 kg S and 2 kg Zn per hectare along with recommended dose of N, P, and K is necessary for obtaining maximum grain yield as well as straw yield of T-Aman rice.

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ABBREVIATIONS AND ACRONYMS

AEZ	:	Agro-ecological Zone
ANOVA	:	Analysis of Variance
BARC	:	Bangladesh Agricultural Research Council
BARI	:	Bangladesh Agricultural Research Institute
BAU	:	Bangladesh Agricultural University
BBS	:	Bangladesh Bureau of Statistics
BCR	:	Benefit Cost Ratio
BRRI	:	Bangladesh Rice Research Institute
CGR	:	Crop Growth Rate
CV	:	Coefficient of variation
DMRT	:	Duncans Multiple Rang Test
FAO	:	Food and Agricultural Organization
Fig	:	Figure
FRG	:	Fertilizer Recommendation Guide
IRRI	:	International Rice Research institute
LSD	:	Least Significant Difference
MOP	:	Muriate of Potash
PPM	:	Parts per million
RCBD	:	Randomized Complete Block Design
SE	:	Standard error of means
SFFP	:	Soil fertility and fertilizer Management Project
TSP	:	Triple Super phosphate
USDA	:	united States Department of Agriculture

introduction

INTRODUCTION

The crop production in Bangladesh is dominated by intensive rice cropping covering about 80% of arable land and the most dominant cropping pattern is Boro-T. Amon rice. Out of total rice production in this country, about 45% come from aman rice (BBS 2006).Although Bangladesh ranks 4^{th} in the world both in acreage and production of rice, it ranks 39^{th} in yield (IRRI, 2003). The average yield of rice is low (3.44 t/ha) compared to other rice producing countries such as China, Korea, Japan and USA where per hectare yield is 6.26, 6.23, 6.58 and 7.37 ton/ha ,respectively (FAO, 2003).

Soil fertility management has significant importance to increase crop productivity. Unfortunately fertility of the soil this country has been deteriorating over the years which are responsible for stagnating or declining crop yields. Plant nutrients in soil, whether naturally endowed or artificially maintained, is a major determinant of the success or failure of a crop production system. The crop production system with high yield targets can not be sustainable unless nutrient inputs to soil are at least balanced against nutrient removal by crops (Bhuiyan *et al.*, 1991). In Bangladesh the use of chemical fertilizers as a supplemental source of nutrients has been increasing steadily, however they are not usually applied in balanced proportions (BARC, 1997). Hence, a pragmatic step needs to be taken for balanced application of fertilizer with the limiting nutrient elements wherever necessary.

The farmers of Bangladesh use only about 172 kg nutrients/ha annually (132 kg N,17 kg P, 4 kg S and 2 kg Zn +B+ others),while the crop removal is about 250 kg/ha (Islam, 2003). Consequently, in addition to N, P and K deficiencies, some other nutrients such as B, Zn and S deficiencies are being observed in many parts of the country.

Sulphur deficiency is a common nutritional problem of wetland rice. Sulphur and nitrogen are both constituents of plant protein and a critical N:S ratio of rice plant at the maximum tillering stage has been estimated to be 15:1 (Islam and Ponnamperuma, 1982). Sulphur deficiency affects not only the growth and yield of rice but also the protein quality through its effect on the synthesis of certain amino acids such as cystein, cysteine and methionine. Zinc also plays a vital role in the physiological process of rice plant such as cell elongation, protein synthesis, meristematic tissues development and ribosome formation (Gupta *et al.*, 1995).

Both S and Zn deficiencies arise in wetland rice soils mainly because of formation of insoluble ZnS. Sulphur deficiency in rice in Bangladesh was first detected at BRRI farm at Joydebpur in 1976 (Islam, 1978). About 0.80 million hector are suspected to be potentially sulphur deficient in Bangladesh (BRRI, 1982). The use of almost sulphur free fertilizer such as Urea and triple super phosphate (TSP) may be an important reason for widespread occurrence of Sulphur deficiency problem. About 1.2 million hectors of land are suspected to be potentially Zn deficient in Bangladesh. The deficiencies of these elements are due to intensive cropping with modern crop varieties with high yield potential.

The farmers of Bangladesh mainly use three fertilizers such as Urea, TSP and MOP, but they seldom use S and Zn fertilizers. Electro- chemical changes of flooded soils such as reduction, pH changes, and the resulting ionic interaction control the micronutrients regime of wetland rice soil. An imbalance of an element results in nutritional disorder or abnormality as retarded growth or lower grain yield. As a result, the benefit of NPK fertilizers can not be achieved fully if there remains nutrient deficiency like S and Zn. So, to increase the production of rice, application of S and Zn to the soil in the form of fertilizer is needed.

OBJECTIVES

I. To develop a suitable dose of Sulphur and Zinc fertilizer for T-Aman (BRRI-31)

II. To see any significance in soil fertility due to use of Sulphur and Zinc fertilizer.

III. To evaluate the effects of different levels of Sulphur and Zinc fertilizers on the yield of T-Amon (BRRI-31)

REVIEW OF LITERATURE

An attempt has been made in this chapter to present a brief and pertinent review of the works in Bangladesh and also in the other parts of the world in relation to the effects of S and Zn on the growth, yields, and nutrient uptake by rice.

2.1 Sulphur

2.11 Forms of S in soils

Sulphur is a macronutrient and it is also known as a secondary nutrient. It occurs in soils in both organic and inorganic forms. Nearly 90% of total S in soils exists in organic forms. The inorganic forms are solution S042, insoluble $S0_4^2$ (co- precipitated with $CaCO_3$) and reduced inorganic S compounds. There are three groups of organic: HI-reducible S. C-bonded S and residual or inert S. The main S bearing mineral is gypsum ($CaSO_4.2H20$) (Stevenson, 1986), others are eposomite ($MgSO_4.7H20$), mirabilite ($Na_2SO_4.10H20$), pyrite (FeS_2) and sphalerite (ZnS). Under submerged condition, S occurs in reduced forms such as FeS, FeS_2 and H_2S.

2.1.2 Status of S in soils

Total S status of soils varied between 23.1 and 369.3 mg/ kg' soils (Singh *et al.* 1995). Total S in mineral soils may range from <20 mg kg^{-1} in sandy soils to >600 mg kg^{-1} in heavy textured soils. Organic soils may contain as much as 0.5% S. Most soils, however, contain 100 to 500 mg kg^{-1} S in soil (Tabatai, 1982). Total S content at different depths varied from 98 to 310 mg kg^1 in Alfisols and from 100 to 387 mg/kg in Vertisols (Padmaja and Raju, 1992; Padmaja *et al.* 1993). The element S occurs in soils in organic and inorganic forms with the organic S accounting for >95% of total S in humid and sub-humid regions.

2.1.3 Functions of S in plants

Plants absorb S in the form of $S0_4^{-2}$. Sulphur carries out many important functions in plants. Sulphur is required for the synthesis of proteins, vitamins, chlorophyll and also required for the synthesis of the S-containing amino acids such as cystine, cysteine and methionine which are essential components of proteins (Tiwari et *al.*, 1997; Tisdale *et al.*, 1997).

Amino acids containing sulphur is important in the synthesis of other compounds within the cell, such as S adenosyl methionine serves as a methyl donor in biosynthesis of many component including chlorophyll, flavonoids and sterols. Ferredoxin is a sulphur containing components that helps in the electron transfer molecule involved in the photosynthesis and in reduction of oxidized compounds such as nitrite. It helps in the synthesis of oils and formation of seeds. Plant membrane structure and function also require 5, suipholipids being essential membrane compounds and intimately involved in organization of chlorophyll in chloroplast lamellae (Smith and Siregar, 1983).

Sulphur is known to stimulate root growth and seed formation (Thompson *et a!.* 1970)

Sulphur deficiency may not reduce yields but can also severely reduce quality (mol% cysteine and methionine in protein) in grain, by changing gene expression of storage protein in developing seeds (Randall *et al,* 1979; Chandler et al., 1983). Sulphur fertilizer can improve nutritive quality and the marketability of several cereal crops (Tiwari *et al.*, 1997).

2.1.4 Deficiency symptoms of S in plants

In rice, there is often general yellowing of the whole plants and it appears similar to N deficiency but the symptoms appear first or most marked on the younger leaves (Rao *et al.*, 1980). Symptoms of S deficiency include reduced growth and chiorosis or yellowish of the leaves due to diminished leaves of chlorophyll (Tabatabai, 1986). Chlorosis extends to the older leaves, redding and purpling develops in the stem and leaves (Yoshida and Chandhury, 1979). Chlorotic plants become stunted, thin stemmed (Tisdale *et al.*, 1997) and spindly (Brady, 1996).

The reasons for S deficiencies are: greater use of S free fertilizers, higher crop removal of S because of higher yields and intensive cropping, increasing depletion of soil S due to wide gap between additions and removal of S, losses of S by leaching, decreased use of S as an insecticide and fungicide, and smaller addition of S through rainfall due to lowering of atmospheric levels of SO_2 and H_2S.

2.1.5 Effects of Sulphur on rice

The effect of S on rice has been studied by many researchers at home and abroad. In this section, a brief review on the pertinent works from 1995 to date has been presented.

Islam *et al.* (1995) carried out a field experiment during aman season of 1992 to investigate the response of BR 31 rice to different nutrients including S. They reported that application of 20 kg S ha^{-1} with 100 kg N ha^{-1} increased the grain yield by 1300 kg N ha^{-1} application.

Mukhopadhyay *et al.* (1995) found that gypsum and pyrite were equally effective in increasing rice yield when applied at the rate of 20 kg S ha^{-1}.

Tupatkar and Sonar (1995) reported that application of 2.5 t ha^{-1} of pyrite increased grain and straw yields of rice over control.

Zia *et al.* (1995) concluded form the studies on the S status of soils under rice based cropping sequences that out of 39 soil samples from rice growing areas in the district of Sheikhupura, Pakistan, none were deficient in S. At a constant level of N application, S concentration and its uptake were higher with ammonium sulphate than with urea. The study showed possible response of rice to S application even the native S status of the soil was well above the critical level.

Tandon et al. (1995) observed that S application of 20 to 60 kg ha^{-1} significantly increased grain yield of rice and the average yield response due to S application was 17.1%. He also noted different sources of S were equally effective.

Chauhan *et al.* (1995) observed that gypsum applied with pressmud gave higher grain yields of 3.92 t ha^{-1} in 1991 and 4.53 t ha^{-1} in 1992, in comparison with 0.68 and 0.73 t ha^{-1}, respectively in control treatments.

Sakal *et al.* (1995) reported that concentration of S in grain and straw and its corresponding uptake increased with increasing rates of S.

Islam *et al.* (1996) conducted field experiments during T. aman season of 1992 to examine the response of BR 11 rice to S, Zn and B. They found that application of 20 kg S /ha at both locations significantly increased the grain yield of rice.

Gupta *et al.* (1997) conducted field experiments in the karif seasons of 1996 and 1997 at one Regional Agricultural Research Station, India to study the effects of sulphur sources sulphur powder, gypsum, iron pyrites) and sulphur dose (0, 10, 20, 30 or 40 kg S ha^{-1}) on rice. They showed that compared with controls, rice grain yield increased by 14.2, 24.2, 25.6 and 20.1% with the four rates of sulphur respectively. The optimum dose was 20 kg S ha^{-1}.

Suwanarit *et al.* (1997) found that moderate application of S fertilizers to a soil deficient in S increased the aroma, softness, and stickiness, and glossiness of boiled milled grains, but higher rates than the optimum decreased these quality parameters. To obtain grains with the highest aroma and stickiness, rates of S fertilizer well above those giving maximum yield were required, such that rice yield decreased to 88% of the maximum. To obtain grains with highest softness and glossiness, S fertilizer rates giving yields 96-98% of the maximum were required. To obtain grains high in all of the five aspects of quality, S fertilizer at the rate-giving maximum or near maximum rice yield should be applied.

Sahu and Nandu (1997) carried out two field experiments, one in black soil and other in laterite soil to determine the response of rice cv. Jajati and Lalat to sulphur (0-60 kg ha^{-1}) in Orissa. They observed that mean grain yield increased with up to 40 kg S ha^{-1} on black soil and the yield was the highest with 60 kg S ha^{-1} on the laterite soil.

Uddin *et al.* (1997) conducted a field experiment in Patuakali during aman season of 1990 to see the effect of N, P, and S on the yield of rice cv. Haloi. They reported that application of 20 kg S ha^{-1} increased tillering, grains $panicle^{-1}$ and grain yield of rice.

Sharma and Gangwar (1997) observed that total S, organic S, heat soluble S, NaH_2PO_4 extractable S and $CaCl_2$ extractable S were correlated significantly and tively with organic carbon and total N contents of Soil.

Patra *et al.* (1998) conducted a greenhouse experiment to study the effect of S application and 5 water management practices on rice in S deficient wetland rice soil. Under continuously flooded condition, rice plants showed characteristic S deficiency symptoms and produced the lowest grain yield. Application of fertilizer S or soil drying for two weeks during active tillering or panicle initiation stage and reflooding increased crop yield by eliminating S deficiency. Soil drying and reflooding influenced Mg, S, Fe, Mn and Cu nutrition of rice favourably which together accounted for 89% variability in rice grain yield.

Sarkunan *et al.* (1998) carried out a pot experiment to find out the effect of P and S on the yield of rice under flooded condition on a P and S deficient sandy loam soil. The treatments were the combination of 4 levels of P (0, 25, 50 and 100 mg kg^{-1} soil) as ammonium phosphate and 4 levels of S (0, 10, 25 and 50 mg/ kg soil) as ammonium sulphate. Increasing levels of P from 0-100mg/ kg progressively increased the grain yield from 16.9 to 42.5 g pot^{-1}. Sulphur addition at 25 mg kg^{-1} resulted in 9% increase in grain yield. The treatment combination of 100 mg P and 10 mg S kg^{-1} soil gave significantly higher grain yield than the other treatments.

Li and Li (1999) conducted pot experiments with rice grown on black soils given NPK (control), NPK+Ca, NPK+gypsum, NPK+S or NPK +Ammonium Sulphate .

Application of ammonium sulphate or elemental S increased yield by 28.8% and 19.7% respectively. In the field experiment S increased yield by 9.7-11.3%. The added element increased plant growth, the number of tillers, grains/ panicle and yield .

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

Ram *et al.* (1999) studied the effect of 2 sources (pyrite and gypsum) and 4 levels of S application (0, 30, 60, and 90 kg ha^{-1}) on growth, yield, S use efficiency and S uptake in rice in a reclaimed salt affected soil in Uttar Pradesh, India. Application of S at 90 kg ha^{-1} gave the highest yield, which was significantly the highest than obtained with application of 30 kg S ha^{-1}.

Wani *et al.* (2000) carried out a field experiment during Aman season 1995 in India with rice given 0, 10, 20, 30, 40, or 50 kg S ha^{-1}. Grain contents of crude protein, methionine and cystine increased with increasing S rates up to 40 kg ha^{-1} and then decreased slightly.

Mandal *et al.* (2000) carried out a greenhouse experiment to evaluate the effect of N and S fertilizers on nutrient content of rice grain (cv. BR 3) at various growth stages (tillering, flowering and harvesting). Nitrogen was applied as urea and S as gypsum at 0, 5, 10, and 20 kg S ha^{-1}. The combined application of these elements increased the straw and grain yield of rice significantly.

Mythili *et al.* (2001) conducted a greenhouse experiment at the Tamil Nadu Agricultural University, India on soils, which are both deficient in S and Zn using rice as the test crop to investigate the effect of green manure (*Sesbania aculeata*) on soil S and Zn availability. The 11 treatments were used as control (T_1), NPK (T_2), NPK+GM (T_3), NPK+$ZnSO_4$ (T_5), NPK+ EDTA-Zn (T_6), NPK + gypsum (T_7), NPK+ GM+ $ZnSQ_4$ (T_8), NPK + EDTA-Zn + GM (T_9), NPK + gypsum + GM (T_{10}) and NPK + gypsum + GM + $ZnSO_4$ (T_{11}) GM application in sandy loam soil showed higher availability of DPTA-Zn, particularly with EDTA-Zn than in clay loam soil.

T_9 enhanced the availability of Zn at active tilléring stage(AT) (2.91 mg kg^{-1}), panicle initiation (PI) stage (3.60 mg kg^{-1}) and harvest stages (2.80 mg kg^{-1}) followed by T_{11}. The highest Sulphur availability was obtained with T_{11} at (21.38 mg kg^{-1}) and PI (20.13 mg kg^{-1}) and with T_{11} at harvest stages (26.38m g kg^{-1}).

Sakal *et al.* (2001) conducted field experiments in Bihar, India to determine the direct effect of soil (Ustifluvents) applied with Sulphur (S) on succeeding wheat and rice crops. Sulphur was applied at 0, 15, 30 and 45 kg S h^{-1} a as single super phosphate containing 12% S, and rice cv. Rajshree was grown as a test crop. A basal dose of 110 kg N, 60 kg P_2O_5 and 5 kg Zn ha^{-1} was applied as urea, DAP (diammonium phosphate), MOP (muriate of potash) and ZnO ,respectively. The remaining amount of P_2O_5 in 15 and 30 kg S ha' treatments were balanced through DAP. After the first rice crop harvest, 3 more crops (wheat, rice and wheat) were grown in succession without S application to determine the residual effect of S on these 3 crops. Rice leaf sample analysis exhibited higher magnitude of S deficiency than wheat leaf samples. Magnitude of S deficiency based on soil analysis was on an average 25% while the extent of S deficiency based on plant analysis was 58%. Total S in soil was positively and significantly correlated with pH, electrical conductivity, and organic carbon, available P_2O_5 and K_2O, whereas soil available S was positively and significantly correlated with total S. Direct effect of S produced the maximum grain yield of rice (14.3 q ha^{-1} at 45 kg S ha^{-1}). The residual response of 45 kg S ha^{-1} in the second wheat crop, third rice crop, and fourth wheat crop was 14.8, 5.2, and 7.5 q ha^{-1} respectively. Sulphur intake by crops increased progressively with increasing levels of sulphur

Raju and Reddy (2001) conducted field investigations at Agricultural Research Station, Maniteru, Andhra Pradesh, India to study the response of both hybrid and conventional rice to sulphur (at 20 kg ha^{-1}) and zinc (at 10 kg ha^{-1}) applications. Conventional rice, MTU 2067 out yielded the hybrid rice MUT-HR 2003 by 21%. Significant improvement in grain yield was observed due to sulphur application. Zinc application failed to improve the yield markedly.

Vaiyapuri and Sriramachandrasekharan (2001) conducted an experiment on integrated use of green manure (12.5 t ha^{-1}) with graded levels of sulphur (0, 20 and 40 kg ha^{-1})

applied through three different sources in rice cv. ADT 37. 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), rice yield (5.07 t kg ha^{-1}) and soil available nutrients (199.5, 13.4, 299.1, 22.8 kg ha^{-1} for N, P, K and S , respectively) were noticed with 40 kg/ha in Tamil Nadu, India. Among the sources, iron pyrite recorded the maximum uptake (111.6, 26.2, 215.4, 22.7 kg ha^{-1} for N, P, K and S respectively) and rice yield (4.97 t ha^{-1}). However, the highest nutrient uptake (127.7, 28.5, 234.8, 25.5 kg ha^{-1} for N, P, K and S , respectively and rice yield 5.3 t /ha) was obtained when green manure was applied along with pyrite at 20 kg S ha^{-1} which was comparable with pyrite applied at 40 kg ha^{-1} in the absence of green manure.

Peng *et al.* (2002) carried out a field experiment where 116 soil samples were collected from cultivated soils in Southeast Fujian, China. 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 of rice plant.

Babu and Hegde (2002) carried out field studies in Andhra Pradesh, India to evaluate the direct and residual effects of Sulphur on rice-sunflower cropping system. The direct effect of Sulphur through single super phosphate on hybrid rice resulted in a significant increase of 21% in grain yield with a S use efficiency of 13 kg grain kg^{-1} at 45 kg S ha^{-1}. The residual effect of this on succeeding sunflower crop resulted in 37% increase in seed yield and 45% increase in oil content.The value cost ratio (VCR) for direct and residual effects were 35 and 23 with a cropping system VCR of 58.

Chandel *et al.* (2002) conducted an experiment to study the effect of S applied to rice and mustard grown in sequence on the growth and yield of rice at the Research Farm, BHU, Varanasi, Uttar Pradesh, India. Four main plots (rice) S rates (0, 15, 30 kg/ ha) and three subplot (mustard) S rates (0, 20 and 40 kg ha^{-1}) were laid out in a split-pilot design and S were supplied as SSP. They stated that increasing S levels in rice significantly improved growth attributes i.e. tiller number, leaf number and dry matter production; yield trait such as harvest index of rice up to 45 kg ha^{-1} .

Sarfaraz *et al.* (2002) conducted a field experiment to determine the effect of different S fertilizers at 20 kg ha^{-1} on crop yield and composition of rice cv. *Shaheen Basmati* in Pakistan. They found that the number of tillers m^{-2}, 1000-grain weight, grain, and straw yield were significantly increased with the application of NPK and S fertilizer compared to the control. They also found that NPK concentrations and their uptake in grain and straw significantly increased with the application of NPKS fertilizers compared to the control.

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.

Singh and Singh (2002) carried out a field experiment to see the effect of different nitrogen levels (50, 100 and 150 kg ha^{-1}) 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 row length, dry matter production, panicles m^{-2} row length, panicle length and grains/ panicle were significant with increasing levels of N and S up to 150 kg N/ ha and 40 kg S / ha respectively. They also found that total N uptake, grain, straw and grain protein yields significantly improved with the increasing level of N and S application being the maximum at 150 kg N /ha and 40 kg S/ ha respectively.

Biswas *et al.* (2004) reported the effect of S in various region of India. The optimum S rate varied between 30-45 kg ha^{-1}. Rice yields increased from 5 to 51%. Across the crops and regions the agronomic efficiency varied from 2 to 27%.

Fluda *et al.* (2004) conducted an experiment at the Soil Science Department of Bangladesh Agricultural University, Mymensingh, to evaluate the suitable extractants for available sulphur and critical limits of sulphur for wetland rice soils of Bangladesh.

Twenty-two soils from 0-15 cm depth were collected from different locations of Old Brahmaputra Flood plains of the country. Both Geographical and statistical methods were used to determine the critical levels of S.

The extractable S of the soils varied considerably with the soils and the extractants used. The ability of the extractants to extract S followed the order: 0.5 M NH_4OAC> 0.5 M $NaHCO_3$> 0.15% $CaCl_2$ > MCP. The critical levels of MCP, $CaCl_2$, $NaHCO_3$ and NH_4OAC extractable S were 9.3, 9.7, 15.8 and 17.8 mg kg^1 respectively in both graphical and statistical methods for rice. The critical limit for plant S was found to be 0.12% at 56 days of crop growth.

2.2. Effect of Zinc on rice

2.2.1 Forms of Zn in soils

Zinc is a micronutrient since it is required relatively to a smaller amount than macronutrients. The forms of Zn in soils are: solution Zn^{2+}, absorbed Zn^{29+} (clay surfaces, organic matter, carbonates and oxide minerals), organically complexed Zn^{2+} and Zn^{2+} substituted for Mg^{2+} in the crystal lattices of clay minerals, and Zn in primary and secondary minerals. Sphalerite (ZnS), smithsonite ($ZnCO_3$), hemimorphite ($Zn_4(OH)_2.Si_20_7.H_20$) are the important Zn containing minerals. Total status of Zn in soil varies from 10 to 300 μg g^{-1}, averagely being 80 μ g g^{-1}.

2.2.2 Status of Zn in soils

Zinc content of the lithosphere is about 80 mg kg^{-1}. The total Zn content in soils ranges from 10 to 300 mg kg^{-1}, the average being 50 mg kg^{-1} (Tisdale *et al.*, 1997). Not all Zn are available to plants, less than 10% is plant available Zn. In Bangladesh, the Zn deficiency is widespread and it is particularly evident in calcareous and wetland rice soils.

2.2.3 Functions of Zn in plants

Plants absorb zinc in the form of Zn^{2+}. The normal concentration of Zn in dry matter of plant ranges from 25 to 150 ppm. Deficiencies are usually associated with leaf concentrations less than 20 ppm and toxicities will occur when Zn leaf concentration exceeds 400 ppm. Zinc deficiencies are widespread through out the world; especially in the rice land of Asia deficiencies occur in neutral and calcareous soils (Tisdale *et al.* 1997).

Zinc is essential for numerous enzyme systems and is capable of forming many stable bonds with nitrogen and sulphur ligands. The important functional role of Zn includes: auxins metabolism, influence on the activities of enzymes (e.g. *dehydrogenase* enzyme and *carbonic anhydrase),* Synthesis of cytochrome c, and stabilization of ribosomal fractions (Tisdale *et al.*, 1997). Zinc can play a significant role in the protection of cells against oxidative stress through activation of superoxide dismutase (SOD) enzyme (Obata *et al,* 1999).

2.2.4 Deficiency symptoms of Zn in plants

Poor growth, interveinal chlorosis and necrosis of lower leaves are the common symptoms of Zn deficiency. In rice, the rusty brown spots on older leaves, white midrib (blanching) of younger leaves, stunted growth and delayed maturity are the symptoms of Zn deficiency. Sometimes the Zn deficiency occurs in patches, not in whole fields. Zinc deficiencies are named as rusty brown spot of rice, white bud of corn, little leaf of cotton, mottle leaf of citrus and fern leaf of potato. Corn and beans are most sensitive to Zn deficiency.

2.2.5 Effects of zinc on rice

Considerable works have been done on Zn nutrition of rice in Bangladesh and also in the other countries of the World. In this section, the works that have been done in 1995 onwards are reviewed.

Khanda and Dixit (1995) stated that rice (cv. Sarathi) grain yield increased with N rates (0 to 60 kg ha^{-1} and the grain and straw yields were further increased by foliar or soil application of Zn. Soil application of Zn gave slightly better results than foliar application.

Ram *et al. (1995)* reported that grain yield was obtained as 2.7 t ha^{-1}without applied Zn and 3.3-4.0 t ha^{-1} in the fertilizer treatments, with the highest yield given by 20 kg $ZnSO_4$ ha^{-1} application.

Ramadass *et al.* (1995) in a few field trials in the Aman season of 1990-91 at Bhavanisagar, Tamil Nadu, and India with 10 rice cultivars using 0, 25 or 50 kg $ZnSO_4$ ha^{-1}. They reported that grain yield increased with up to 25 kg $ZnSO_4$ha-^{1}

Rajan (1995) carried out a green house experiment with rice cv. IR5O in Madukkur series and Nedumbalam series soils and given $ZnSO_4$ (23% Zn), $ZnSO_{4+}$ ammonium polyphosphate (APP), zincated urea (2% Zn) or zincoted m diammonium phosphate (6% Zn) each at a rate equivalent to 25 kg $ZnSO_4$ /ha They found that grain and straw yield and total Zn uptake were highest with $ZnSO_{4+}$ ammonium polyphosphate.

Arif *et al.* (1996) conducted a field trial with rice (cv. Rio Paranaiba) using 0, 5, 10 or 20 kg Zn ha^{-1} and 0, 0.5, 1.0 or 2.0 kg B ha^{-1}. They observed that seed yield was not affected by the treatments, but the yield of whole grain was maximum with 10 kg Zn ha^{-1}.

Devarajan and Krishnasamy (1996) conducted a pot experiment, rice cv. ADT36 was given the NPK with 0, 1.25, 2.5, 3.75, or 5.0 ppm Zn as $ZnSO_4$ or Zn enriched organic manure. They observed that grain yield was highest with FYM composted with 2.5 ppm Zn + green manure.

Khanda and Dixit (1996) stated that application of Zn significantly increased the grain and straw yields over no Zn application. They stated that the application of N and Zn increased the grain yield by 7 2% and straw yield by 12 9% over soil N.

Kumar and Singh (1996) reported that dipping the seedling roots in 2% $ZnSO_4$ solution gave higher yield (5.15 t/ ha) almost similar to the application of 25 kg $ZnSO_4$/ ha compared to control.

Ugurluoglu and Kacar (1996) carried out a greenhouse pot experiment: rice was grown on soils from different rice growing areas of Turkey, and given 0, 2, 4 or 8 ppm Zn as ZnO, $ZnSO_4$ or Zn-EDTA. Compared with control, they found that the maximum increase in dry matter production was obtained with ZnO.

Singh *et al.* (1996) observed that grain yield of rice increased significantly with up to 100 kg N /ha alone or with Zn. Net returns were highest with applying 150 kg N + 25 kg Zn ha^{-1}.

Sarkunan *et al.* (1996) carried out a pot experiment under flooded condition and found that Zn application increased the grain yield of rice.

Islam *et al.* (1997) reported that autumn rice responded significantly to S, Zn and B applications. The highest grain yield (4.5 t/ ha) was obtained in S +Zn+ B treatment with 41.8% grain yield increased over control, while the application of S, Zn or B alone gave yield increased of 23.3, 21.7 and 14.6% , respectively.

Ingle *et al.* (1997) conducted a field trail at Sindewahi, Maharashtra, India, using rice cv. Sye-75 given 0, 5, 10 or 15 kg Zn ha^{-1} as $ZnSO_4$ or ZnO. They observed that grain yield was increased with increasing Zn rates but was not affected by sources of Zn.
Agarwal *el al.* (1997) conducted field trials on rice-wheat cropping pattern at Kanpur, India, in 1990-93. They reported that mean yield of each crop and net returns were greatest when crop was given 25 kg Zn SO_4 ha^{-1}.

Chen *et al.* (1997) carried out a field experiment at the Rice Research Institute of Yunnan Agricultural University, Kunming, on soils low in Zn with rice cultivars Xunza 29, 1-lexi 35 and Yungeng 34 using 0 or 5 kg Zn ha^{-1}. Application of Zn significantly increased yield. Grain amylose contents of milled rice were also increased by Zn application.

Sakal *et al.* (1997) reported that the continuous rice-wheat cropping system with increasing NPK fertilizer applications is the cause of depleting the soil available micronutrients reserve, particularly available Zn, leading to decline in crop productivity.

Trivedi and Verma (1997) carried out field trials in the 1992 and 1993 seasons; rice cv. Java and BR11 were given 0, 5, 11.2, or 16.8 kg Zn ha^{-1}. The experimental soil was low in DTPA extractable Zn (0.06 mg kg^{-1}) with pH of 7.9. Applied Zn increased crop yield and Zn uptake, with quadratic relationships with application rate. Economic analysis indicated an optimum application rate ofl19-kgZnha^{-1}

Binod *et al.* (1998) conducted an experiment on rice (cv. Sita) grown in the nursery giving soil application of 0, 12.5 or 25 kg $ZnSO_4$ ha^{-1}, foliar spray of 0.5% $ZnSO_4$ solution 3 weeks after sowing or dipping seedling roots in 2% ZnO suspension. They obtained the best results with applications of 25 kg $ZnSO_4$ ha^{-1} followed by spraying with 0.5% $ZnSO_4$ solution 3 weeks after transplanting or dipping seedling roots in 2% ZnO suspension. Zinc application in the nursery was effective in correcting Zn deficiency and improving yield even when Zn was not applied after transplanting.

Bansal *et al.* (1998) reported that higher levels of Zn in soil decreased the absorption and translocation of Mn, Cu, and Fe in plants. The decrease in plant Mn concentration resulted the appearance of Mn deficiency symptoms in rice despite its adequate level in soil.

Chitdeshwari and Krishnasamy (1998) studied the effect of different levels of Zn and Zn enriched organic manures on the availability of micronutrients under submergence in Zn deficient rice soils. The application of 2.5 mg kg^{-1} Zn enriched with farmyard manure +leaf manure increased the Zn status at all stages of crop growth.

Islam and Haque (1998) cited from two different sites on farm experiments on 'rice based cropping pattern that the uptake of KS decreased very much when low rate of N and Zn were added at Palima, Tangail site. At Palasbari, Gibandha site the uptake of NPK also markedly decreased when no zinc was added in the system.

Ahmed and Hossain (1999) reported from three years field experiments of wheat-mungbean-rice cropping sequence that application of Zn along with NPKS increased rice yield.

Singh *et al.* (1999) carried out a long term experiment under International Network on soil Fertility and Sustainable Rice Farming at GB Pant University of Agricultural and Technology in India coordinated by IRRJ. Manila to study the effect of decade long fertilizer and manurial treatments on soil pH, fertility and productivity of a rice cropping system in a Mollisol. The treatment included various combinations of N, P. K, Zn and FYM. After 10 years of continuous intensive cropping under various fertilizer and manurial treatments, the differences in the values of soil pH, organic matter, available P. K, S, B, M_o and DTPA extractable micronutrient contents in soil at 20 cm depth and crop Productivity were found to be statistically significant. The grain yield of rice and wheat in balanced fertilizer treatments viz. NPK + FYM and NPK + FyM +ZN foliar were maintained during this period.

Sharma *et al.* (1999) conducted field experiments in 1995-96 at Hanumangarh, Rajasthan India, with rice cv. Java and PR 106 given 0, 12, 24 or 36 kg $ZnSO_4$/ ha at 30 or 30 + 45 days after transplanting. Yields increased with increasing rate of Zn application, with 36 kg Zn/ha giving the maximum yield, followed by two spraying.

Slaton *et al*. (2001) reported that Zn is the most growth and yield limiting micronutrient in US rice (*Oryza* sativa) production. They conducted two field studies to evaluate several dry, granular and liquid Zn sources applied at preplant incorporated (PPI), pre-emergence (PRE) and pre-flood (PF) for rice yield in Arkansas, USA. Application of liquid chelated and inorganic Zn sources at rates from 1 to 2 lb Zn $acre^{-1}$ produced high yields across application times. Application of dry granular Zn sources preformed the best when applied at either PPI or PRE.

Vasudeva and Ananthanarayana (2001) conducted a field experiment in India to investigate the effect of added Zn based on Zn absorption maximam on rice yield and nutrient dynamics in acid soils (Ulti Paleusalf). The treatments comprised different levels (0, 2.2, 10, 20 and 40 kg ha^{-1}, which correspond to 0, 0.22, 0.55, 1.10, 1.65 and 2.20% of zinc absorption maxima) and sources of Zn ($ZnSO_4$ and ZnO) along with recommended dose of farmyard manure (5 t ha^{-1}) and fertilizers N, P_2O_5 and K_2O ha^{-1} (75 :75: 90). Results showed that the paddy rice responded well to Zn application at 20 kg $ZnSO_4$ /ha in acidic soils, which gave a maximum grain yield of 7002 kg ha^{-1}. With regards to Zn source, the plants, which received Zn as ZnO, showed lower yield compared ton Zn as $ZnSO_4$ this could be attributed to the lower solubility of ZnO. Antagonistic effect on the availability and uptake of Zn were on observed due to increased solubility of Fe and Mn upon submergence. Zn concentration in soil after harvest ranged from 1.96 to 18.52 μg g^{-1}. It is suggested that $ZnSO_4$ at 20 kg ha^{-1} can be used to produce the maximum grain yield and nutrient dynamics of wetland rice.

Ullah *et al.* (2001) conducted an experiment to study the effect of $ZnSO_4$ (0, 10 20 kg ha^{-1}) on rice cv. BRRI dhan 30 in Mymensingh, Bangladesh. $ZnSO_4$ along with 60 kg P_2O_5 ha^{-1}, 40 kg K_2O ha^{-1} and 80 kg N ha^{-1} were applied to the plot. They found that plant height, tiller number, 1000-grain weight, grain and aw yields; and grain, straw and soil Zn contents increased with $Zn50_4$ application. They also found the tallest plants (75.67 cm) and the highest number of tillers (10.6 per hill), 1000-grain weight (28.7g) and straw (101.93) ppm and grain (73.33 ppm) Zn contents were obtained with 20 kg $ZnSO_4$ ha^{-1}.

Venna *et al.* (2001) carried out a field experiment at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India, where three levels of Zn sulphate (0, 20 and 40 kg/ ha) were tested in paddy grown after paddy nursery. The results indicated that the use of $ZnSO_4$ did not have significant effect on grain yield and yield attributes in rice particularly grown after rice nursery in which nursery was fertilized at 20 kg $ZnSO_4$ ha^{-1}.

Abid *et al.* (2002) studied the effect of Zn, Fe and Mn on yield contributing parameters and mineral contents of rice in 10 kg sandy clay loam soil pot^{-1}. Two rates of Zn (0 and 5 or 10 mg kg^{1} soil) and one rate each Fe and Mn (5 mg kg^{-1} soil) along with a basal dose of NPK (100:50: 50 mg kg^{-1}) was added. They stated that the number of tillers /hill, number of grains $panicle^{-1}$, 1000-grain weight, and grain yield increased significantly with application of Zn, Fe and Mn alone or various combinations. They also stated that, additional increase in rice yield and yield contributing growth parameters were noted in treatment comprising 10 mg kg^{-1} Zn along with 5 mg kg^{-1} Mn and basal dose of NPK fertilizer.

Bhat *et al.* (2002) carried out a field experiment at Rice Research and Regional Station SKUASTK Khudwanf (Kashmir, India) to study the efficiency of various cultural management practices for improving the yield attributing characters and. grain yield of rice. Treatments comprised a control; recommended fertilizer dose (RFD; 80: 45: 20: P_2O_5: K_2O kg had) with 20 ×10 cm spacing. RFD + farmyard manure (FYM) at 10 t ha^{-1} with 20 x 10 cm spacing; 15% RFD with 20 × 10 cm spacing; RFD+15 kg $ZnSO_4$ ha^{-1} with 20 × 10 cm spacing; local practice (60: 40: 0 N: P_2O_5: K_2O) with random spacing and RFD with random spacing. The result of two years study revealed that application of 15 kg $ZnSO_4$ in addition to RFD with optimum plant population (4.4 lac ha^{-1}) proved significantly superior to the other treatment combinations. The yield advantage obtained by applying $ZnSO_4$ with RFD was 22.7% over RFD alone and 12% over RFD +10 t FYM ha^{-1}. Mean maximum panicle number and panicle weight were also recorded with the application of $ZnSO_4$ + RFD, which led to higher grain yield of the crop.

Dunn *et al.* (2002) conducted an experiment on the effect of soil pH and Zn on rice cv. Cypress, Kaybonnel and Drew on a Crowley slit loam soil (fine, montmorillonite, thermic Typic Albaqualf) at Qulin, Missouri, USA. Their experiment was split-plot; main plots continued rice cultivars, subplots had annual applications of lime and Zn treatments were untreated, soil applied Zn as $ZnSO_4$, and foliar applied Zn as Zn-EDTA chelate. After two years, they found that, lime application increase soil pH from 6.01 to 7.2. They stated that soil pH had a significant effect on the extractable Zn following two years of applying $ZnSO_4$ fertilizer but soil pH did not significantly affect plant Zn concentrations. They concluded that soil applied Zn fertilizer increased Zn concentrations in plant tissue more than foliar Zn.

Kumar *et al.* (2002) studied the effects of Zn source ($ZnSO_4$. ZnO or chelated Zn) and Zn and P rates (0, 10, 20 or 30 ppm) on the performance of rice cv. Saket 4 in Lalthaoit, Butandshahr, Uttar Pradesh, India. Among the various Sources of Zn, they found that chelated Zn resulted in the maximum grain (2 923 t ha^{-1}) and straw (4. 861 t /ha) yields nitrogen (1.16%), phosphorus (0.28%), potassium (0.54%) and Zn (5.19%) contents of straw. Among Zn rates, 10 ppm gave the maximum grain (3.0 t ha^{-1}) and straw (4.83 t ha^{-1}) yield. They also found that Zn content of grain (2.30 ppm) and straw (5.32 ppm) was highest at 30 ppm.

Lora *et al.* (2002) conducted an experiment to determine the effect of Zn (at 0, 8, 24 and 32 kg ZnO ha^{-1}) on yield and quality of three rice varieties (cv. R-1, Selecta and Thilandia-III) on a Typic Tropaquept with low Zn content located in Villanueva, Casanare, Colombia. The best effect on yield was observed at 16 kg/ ha for R-1, Selecta and Thilandia-III. A significant effect on the number of grains panicle' and 1000-seed weight was also observed.

Singh and Nongkynrih (2002) conducted a field experiment at the North Eastern Hill University, Shillong, Meghalaya, India, to elucidate the distribution, adsorption and utilization of Zn in wetland soils, and its uptake by plant from nutrient solutions. It is concluded that the use of Zn fertilizers increased the yield of rice in wetland soils of Meghalaya. The results further indicated that only rice plants could utilize a fraction of total quantity of applied Zn. The availability of residual Zn for the next crop was also very low.

Mythili *et al.* (2002) conducted a greenhouse experiment on two Zn deficient soils using rice as a test crop to investigate the effect of green manure *(Sesbania aculeata)* on the relatively efficiency of applied Zn. Radio-tracer viz., ^{65}Zn was tagged to two sources of Zn ($ZnSO_4$ and EDTA-Zn at 5 kg Zn ha^{-1}) to determine the contribution of fertilizer sources. Intercorporation of *Sesbania aculeata* at 10 t ha^{-1} could contribute approximately 64, 4, 42, 0.6 and 11 kg of N, P, K, and Zn and S ha^{-1}, respectively. The beneficial effect of integrated use of green- manure (GM) with inorganic fertilizer nutrients particularly, $ZnSO_4$ in clay loam and EDTA-Zn in sandy loam soil was evident due to higher uptake and increased dry matter yield obtained at harvest NPK + gypsum+ GM+ $ZnSO_4$ application recorded the highest grain, straw and root yields in both the soils.
The highest total Zn uptake of 3.87 mg' pot/ with NPK+ gypsuni+ GM +$ZnSO_4$ application and greater percentage of fertilizer Zn derivation was observed with NPK+$ZnSO_4$ (86.20%) followed by NPK+EDTA-Zn alone. Zn utilization from fertilizer and use efficiency was found to be greater when the Zn sources particularly, $ZnSO_4$ was applied.

Malavolta *et al* (2002) conducted a field experiment with two rice cultivars, IAC 165 and JAC 202, which were grown in nutrient solution with four Zn rates: 0.000, 0.065, 0.130 and 0.325 mg $liter^{-1}$. At harvest, the plants were split into roots, culms with leaves, rachis and grains. The dry matter of the various parts, 100-seed weight, and Zn content of culms plus leaves were determined. On the average of the Zn rates applied, the cultivars showed significant response in yield. The micronutrient affected dry matter production of all plant parts, except of rachis. The highest grain yield was obtained upon treatment with 0.065 mg liter^{-1} Zn in which IAC 202 showed higher production; at the two higher rates, a decrease was observed in the total dry matter and grain production associated with excess Zn in culms with leaves. A significant correlation was found between Zn rates and grain quantity. Positive correlations were observed between rates and Zn content of the aerial parts and of the grains. Grain production was not related to Zn level in cuims with leaves. The efficiency of Zn use for yield formation was higher in IAC 202 than in JAC 165.

Prasad *et al.* (2002) conducted a field experiment in Bihar, India, for five years to study the optimal frequency of Zn fertilizer application on Zn deficient soil in the rice-wheat cropping system. The treatments were soil and foliar application of $ZnSO_4$ at different doses. The results indicate that the pooled yield of rice (32.5 q ha^{-1}) was higher than that of wheat grain (15.8 q ha^{-1}). The frequency of Zn application, based on 10 cropping systems, indicates that the use of 25-kg $ZnSO_4$ ha' as soil application after a two-crop interval was found to be optimal

The rates of increase in yields of rice and wheat were 52.4 and 21.0 kg of $ZnSO_4$, respectively and the percent increase in yield of rice was 46.6 and 38.1. The rice and wheat yields in the cropping system were significantly correlated with Zn removal.

Minnatullah *et al.*, (2002) conducted a pot experiment to evaluate the incidence of Helminthosporium blight in the cultivars of Boro rice (Gautam, Annada and RAU 1345). They stated that among the five micronutrients treatment ($ZnSO_4$, $FeSO_4$, $MnSO_4$, $CuSO_4$ and control). $ZnSO_4$ spraying Boro rice showed the lowest disease severity and highest grain yield and among the Boro Varity RAU 1345 showed the lowest disease severity.

Das *et al.* (2002) conducted an experiment with Zn which may be an important criterion in minimizing the intensity of Zn deficiency in rice; chelated form of Zn like Zn EDTA (Chelamin) may play an important role in increasing the use efficiency of applied Zn in rice. Treatments used in the experiment were: T_0, control (no application of Zn); T_1, 10 kg ha^{-1} Zn-EDTA as basal; T_2, 20 kg ha^{-1} Zn-EDTA as basal; T_3, 10 kg ha^{-1} Zn-EDTA as grand tillering +10 kg ha^{-1} at panicle initiation stage; 14, 10 kg ha-[1] $ZnSO_4.7H20$ as basal; T_5, 20 kg ha^{-1} $ZnSO_4.7H_20$ as basal and T_6, 10 kg h⁻a $ZnSO_4.7H_20$ as grand tillering +10 kg/ ha at panicle initiation stage. All the treatments received NPK at the recommended rate of 100, 50, and 50 kg ha^1 respectively in a randomized block design replicated thrice. Due to the application of chelated Zn, Zn-EDTA (Chelamin) the result show that the straw and grain yields have been found to be significantly and positively correlated with the periodic Zn content in soils. However, the yield of rice grain has been recorded to be more significantly correlated with Zn content in soil particularly at the later periodic of crop growth suggesting that Zn has contributed more towards the yield of both straw and grain .

Mythili *et al.* (2003) reported that Zn act as important element for favouring the utilization of nutrients present in green manures under submerged condition. They observed this result at Tamil Nadu Agricultural University, India. They also stated that micronutrient cycling in soils is closely associated with organic matter turnover because it is intricately related with trace elements.

Kulandaivel *et al.* (2003) conducted a field experiments at Indian Agricultural Research Institute, New Delhi, India to determine the optimum dose and suitable mode of Zn and Fe application on the productivity of rice hybrid Pro. Agro. 6207 and its residual effect on succeeding wheat (cv. HD 2309). The treatments comprised $ZnSO_4$ at 10, 20, 30 and 40 kg ha^{-1} and $FeSO_4$ at 5 and 10 kg ha^{-1}. $ZnSO_4$ had a positive response on the number of tillers m^2, dry matter production, and leaf area index and crop growth rate. The maximum dry matter (162.80 g ha^{-1}) at harvest was recorded with the application of 40kg $ZnSO_4$ ha^{-1}. The successive increase in the rate of $ZnSO_4$ and $FeSO_4$ had a positive effect on the grain and straw yields of rice. However, it was significant only up to 30 kg $ZnSO_4$ ha^{-1}. On an average, a 15% increase in grain yield, due to 30 kg $ZnSO_4$ ha^{-1}, was recorded compared to the control.

Jadhav *et al.* (2003) studied the effect of Zn fertilizer with or without farmyard manure (FYM) on the performance of rice cv. Ratnagiri grown on lateritic soil (Fluventic

Ustropepts) in Konkan, Maharashtra, India. They considered the treatment consisted of NPK (recommended rate of 100: 50: 50 kg ha^{-1}), NPK + Zn at 15, 30 or 45 kg ha^{-1}, NPK+FYM (10 t ha^{-1}) and NPK+ FYM+ Zn at 15, 30 or 45 kg ha^{-1}. They also found that, the application of NPK+ FYM+ Zn at 30 kg ha^{-1} resulted in the highest total N (97.10 kg ha^{-1}) and P uptake (12.0 kg ha^{-1}), whereas NPK+ Zn at 15 kg ha^{-1} gave the highest total K uptake (128.2 kg ha^{-1}. Lastly, they suggested that, Zn fertilizer rate could be reduced by the incorporation of FYM.

Oliveira *et al.* (2003) evaluated the effect of the rate of Zn-oxysulphate, in granular and powder forms, on two rice cultivars on a Red Lotosol (Hapludox) under greenhouse conditions. Lime, micronutrients, and macronutrients except Zn were applied to all plots. Zn rates were 0, 1, 2, 5 and 10 mg dm^3 of soil and four mg dm^3 were used as the standard source of this nutrient. They stated that power oxysulphate in JAC 165 and granular oxysulphate in IAC 202 resulted in grain yield is similar to those obtained with $ZnSO_4$ used as the control, they found that IAC 202 was more efficient in Zn utilization for vegetative growth and grain yield.

Bandara *et al.* (2003) reported that, a combination of 100 kg N / ha and 2.5 kg Zn/ ha give the same yield as that of 125 kg N/ha alone i.e. there is a direct effect of Zn on N use efficiency, recovery, growth and grain yield of rice.

Khan *et al.* (2003) conducted a field experiment at the Research area of Faculty of Agriculture Gomal University, Dera Ismil Khan (Pakistan) to Investigate the comparative effect of three different methods of Zn application, aimed at alleviating Zn deficiency in transplanted flooded rice (cv. IRRI.6) grown in alkaline calcareous soil and also to evaluate the comparative effect of Zn levels applied by different methods. Among the three methods i.e. nursery root dipping in 1.0% $ZnSO_4$ 0.20% $ZnSO_4$ solution spray after transplanting and 10 kg Zn ha^{-1} day field broadcast method; the last one is more superior, because it produced significantly higher paddy yield. It also observed that a significant increase in Zn content of rice leaf before and after flowering and a significant decrease in P contents of straw and paddy and starch content of paddy were recorded for all methods.

2.3 Combined effects of S and Zn on rice

Idris and Jahiruddin (1982) conducted a field experiment at BAU farm during Boro season to assess the effect of Zn and S on rice yield using BR3 variety. Zinc and S were applied alone and in combination at the rate of 20 kg $ZnSO_4$ /ha and 100 kg gypsum/ ha Grain yield increased significantly due to Zn and S treatments. The maximum yield of 4900 kg ha^{-1} (10% increases over control) was recorded due to combined application of Zn and S.

Hossain *et al.* (1989) reported that application of S and Zn alone or in combination significantly increased the grain yield of BR4 rice under both moist and submerged conditions.

Khan *et al.* (1991) carried out an experiment with rice cv. BR10 on a saline, silty clay loam soil in Bangladesh. They found that grain yields 3.76-6.8, 1.76-2.27, and 0.94-1.40 t ha^{-1} using irrigation water of 1.9, 8, and 6 ds m^{-1}, respectively. At each salinity level, application of gypsum (160 kg gypsum ha^{-1}) + Zn (5 kg Zn ha^{-1}) produced the highest yield.

Hoque and Jahiruddin (1994) reported the effects of single and multiple applications of Zn and S in a continuous rice cropping system on loam soil were investigated at Mymensingh, Bangladesh. The treatments were S alone, Zn alone and S + Zn, each added to the first crop, 1^{St} and 2^{nd} crops or all 3 crops. The rate of S was 20 kg ha^{-1} (gypsum) and that of Zn was 10 kg/ ha. Rice cv. BR3 was grown as the first and second crops (grown in boro season) and cv. BR 11 as the crop (grown in aman season). Crop yields were increased by S but not generally by Zn. Gypsum applied to the 1^{st} crop still increased grain yield in the 3^{rd} rice crop, but although the residual effects were significant the higher were given by gypsum application to all 3 crops.

Akter *et al.* (1994) conducted a field experiment on slit loam and sandy soil loam soils in farmer's fields at 4 sites in Bangladesh. At one site, the grain yield increased while at the other site, the yield decreased due to S application. There was no yield response to Zn application. At one site, 50 kg S + 5 kg Zn ha^{-1} gave the highest grain yield (5.98 t ha^{-1} compared with the control yield of 4.6 t ha^{-1}) while at the other site, the 25 kg S +10 kg Zn ha^{-1} decreased grain yield.

Chowdhury *et al.* (1996) observed that application of S and Zn alone or in combination increased the grain and straw yields of rice and yield components. They found that the maximum yield showing 33.6% increase over control statistically indicated with the yields obtained from the yields obtained from the treatments $Zn_{12}S_{45}$, Zn_8S_{45} and $Zn_{12}S_{30}$ The straw yield ranged from 5.1 t ha^{-1} in Zn_0S_0 treatment to 6.6 t ha^{-1} in $Zn_{12}S_{45}$

Khan *et al.* (1996) observed that the combined application of gypsum and Zn at the rates of 16 and 5 kg ha^{-1} respectively produced 49, 45 and 41% more grain yields above control at 0.6, 8 and 16 m mhos/cm levels of salinity, respectively. They further noted that combined application of gypsum and Zn was effective in increasing protein concentrations in rice grains and total concentrations of Ca, Mg and K in plant tissue

Islam *el al.* (1997) conducted field experiments on a slit loam soil (Aeric Haplaquept) to study the effect of S, Zn and B applications on autumn rice and their residual effects on the following mustard crop. They obtained the highest grain yield of 4.5 t ha^{-1} in S+ Zn+ B treatment with a record of 41.8% yield increase over control while the application of S alone brought 23.3 percent yield increase.

Mandal and Halder (1998) conducted a pot experiment using rice cv. BR 11 with all combinations of 0, 4, 8 or 12 kg Zn /haand 0, 5, or 20 kg S ha^{-1}'. Addition of 8 kg Zn+ 20 kg S ha^{-1} gave the best performance in growth and yield of rice.

Uddin *et al* (2002) conducted a field experiment to study the effects of S, Zn and B supplied from chemical fertilizers and poultry manure on yield and nutrient uptake by rice (cv. BRRI Dhan-30). There were ten treatments. The rate of different nutrients were

100 kg N ha^{-1} from urea, 30 kg P ha^{-1} from TSP, 60 kg K ha^{-1} from MP, 20 kg S ha^{-1} from gypsum, 2 kg Zn ha^{-1} from zinc oxide, 1 kg B ha^{-1} from borax and 4 t poultry manure ha^{-1}. The experiment was laid out in a randomized complete block design with 3 replications. Different nutrients significantly increased plant height, effective tillers $hill^{-1}$, filled grains $panicle^{-1}$, 1000 grain weight, grain and straw yields of rice. The highest grain yield of 4850 kg ha^{-1} was obtained when S, Zn and B were applied together with NPK fertilizers which was comparable to the yields obtained when S, Zn or B were applied singly or in combination of two with NPK fertilizers and also with the application of poultry manure with reduced NPK application. The concentrations and uptake of N, P, K and S by grain and straw were higher when poultry manure was used as a source of 5, Zn and B with reduced amount of NPK. It appeared that application of S, Zn and B along with NPK was essential in this soil to get the maximum yield of BRRI dhan 30. If poultry manure can be applied at 4 t/ha the use of NPK can be reduced and S, Zn and B fertilizers may not be needed.

Shukla *et al.* (2002) reported that the present status of Indian soils indicates that the sulphur and zinc deficiency is increasing. Approximately 25 and 50% of the total cultivated area of the country are estimated to be affected by deficiency of sulphur and zinc, respectively. The rice and coarse cereal based cropping systems experimented in arid, semi-arid, humid and coastal ecosystems have proved that the deficiencies of S and Zn in the soils are responsible for slow growth in food grains production in the country.

Mythili *et al.* (2003a) conducted a field experiment at Tamil Nadu Agricultural University, India. They stated that the effects of green manure (GM) and inorganic Zn and S fertilizer combinations on the yield of a short duration rice cultivar (ADT 36). NPK (100: 50: 50 N: P_2O_5: K_2O kg ha^{-1}) respectively Zn as $ZnSO_4$ (5 kg Zn/ ha) and S as gypsum (50 kg ha^{-1}) coupled with green manure produced the highest grain (5627 kg/ ha) and straw (5723 kg ha^{-1}) yields.

Mythili *et al.* (2003b) conducted a greenhouse experiment to study the effect of green manuring with *Sesbania aculeata* and two Sources of Zn ($ZnSO_4$ and ZnEDTA at 5 kg Zn /ha) and S (gypsum at 50 kg ha^{-1}) on the yield and Zn and S uptake of rice grown on clay loam and sandy loam soils. NPK at 100: 50: 50 kg ha^{-1} respestively manuring resulted in the highest grain yield for both clay and sandy loam soils (46.8 and 39.4 g pot^{-1} respectively). The uptake of Zn and S significantly increased with green manure application in addition to improved soil fertility.

materials and methods

Materials and methods

This chapter describes the experimental aspects of the study. The experiment was conducted at Sher-e-Bnagla Agricultural University farm with (cv. BRRI dhan 31) under some selected treatments. Chemical analysis of soil and plant (grain and straw) was carried out in the laboratory. This section for convenience of presentation has been divided into various sub-sections such as site and soil, climate, crop and variety, land preparation, experimental design, treatments, fertilizer application, sowing and transplanting, intercultural operations, harvesting and threshing, data collection, soil analysis, plant analysis and statistical analysis.

3.1 Experimental site

The experimental field was located at 23°77′ N latitude and 90°3 E longitudes with an elevation of 1.0 meter above sea level.

3.2 Soil

The soil of the experimental field belongs to the Tejgaon soil series of the Madhupur Tract (Agro ecological zone-28).The general soil type if the experimental field is Deep Red Brown Terrace soil. Top soil is silt clay loam in texture. Organic matter content is very low(1.34%) and soil pH varies from 5.8-6.0. The land is above flood level and well drained. The initial morphological, physical and chemical characteristics of soil are presented in Tables 1and 2.

3.3 Climate

The annual precipitation of the site was 2152 mm. The average maximum temperature was 30.34°C and average minimum temperature was 21.21°C. The average mean temperature was 25.07°C. Temperature during the cropping period was ranged between 12.20°C to 29.2°C. The humidity varied from 73.52% to81.25%

R-1	R-2	R-3
S_2ZN_0	S_3ZN_0	S_0ZN_1
S_0ZN_0	S_1ZN_0	S_3ZN_2
S_3ZN_0	S_2ZN_1	S_2ZN_0
S_1ZN_1	S_0ZN_1	S_1ZN_2
S_1ZN_2	S_2ZN_0	S_1ZN_0
S_0ZN_1	S_3ZN_1	S_0ZN_0
S_2ZN_2	S_0ZN_2	S_3ZN_1
S_1ZN_0	S_1ZN_1	S_0ZN_2
S_3ZN_1	S_3ZN_2	S_2ZN_2
S_2ZN_1	S_0ZN_0	S_1ZN_1
S_3ZN_2	S_2ZN_2	S_3ZN_0
S_0ZN_2	S_1ZN_2	S_2ZN_1

Row to Row =2m
Plot to Plot = 0.5m
Plot Size =

Fig- 1 layout of experiment plot.

Table 1. Morphological characteristics of experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agril. University Farm
AEZ No. and name	AEZ-28, Modhupur Tract
General soil type	Deep Red Brown Terrace soil
Soil series	Tejgaon
Topography	Fairly leveled
Depth of inundation	Above flood level
Drainage condition	Well drained
Land type	High land

Table 2 Physical and chemical properties of the experimental soil

Soil properties	value
A. Physical properties	
1. Particle size analysis of soil.	26
%Sand	45
%Silt	29
%Clay	Silt loam
2. Soil texture	
B. Chemical properties	
1. Soil pH	5.7
2. Organic carbon (%)	0.686
3 Organic matter (%)	1.18
4. Total N (%)	0.032
6. Available P(ppm)	19.85
7. Exchangeable K(me/100 g soil)	0.12
8 Available S (ppm)	16
9. Available Zn(ppm)	0.8

3.4 Experimental season

The field experiment was conducted during season of 2007. The experimental period was june15 to October 25.

3.5 Land preparation

Land preparation was started in the 2nd week of July 2007. The land was prepared by repeated ploughing and cross ploughing with a power tiller. Every plougyhing was followed by laddering to have a good tilth. Weeds and stubbles of the previous crop were removed from the field. After leveling, the experimental plots were laid out as per treatments and design.

3.6 Experimental design

The experiment was laid out in a randomized complete block design (RCBD). There were twelve treatments, each replicated three times. The unit plot size was 3m×2m, the plots were separated from each other by 0.5m bunds. There was 2 m spacing between the blocks. The treatments were randomly distributed to each block.

3.7 Treatments

There were twelve treatments with various combinations of Zn and S doses including control. The treatments for T-Aman rice were shown in the Table 3

Table 3 Treatment combinations of S and Zn for T-Aman rice

Treatments	**Combination(Kg/ha)**
T_0	S_0Zn_0
T_1	S_0Zn_1
T_2	S_0Zn_2
T_3	$S_{12}Zn_0$
T_4	$S_{12}Zn_1$
T_5	$S_{12}Zn_2$
T_6	$S_{16}Zn_0$
T_7	$S_{16}Zn_1$
T_8	$S_{16}Zn_2$
T_9	$S_{20}Zn_0$
T_{10}	$S_{20}Zn_1$
T_{11}	$S_{20}Zn_2$

All treatments had received N, P, and K at recommended rate in order to support normal plant growth. The rates and sources of different nutrients used in this experiment is given in Table 4

Table 4 Nutrient elements, their sources, and doses used in the experiment

Nutrient element	**Source**	**Rate(Kg/ha)**
Sulphur (18%)	Gypsum (18%)	0,12,16, 20
Zinc	ZnSO4	0,1, 2
Nitrogen (46%)	Urea (46%)	120
Phosphorus (20%)	TSP (20%)	20
Potassium	MOP (%)	52

3.8 Fertilizer application

Fertilizers were applied to each plot as per treatments. Fertilizer such as urea, TSP, MOP, Gypsum and $ZnSO_4$ were used as source for N, P, K, S, and Zn, respectively. Sulphur and Zinc required for each unit plot were calculated from the rate of application. One –third of urea, MOP and the entire required amounts of other fertilizers were applied as basal to the individual plots during final land preparation. The fertilizers were incorporated into soil by spading. The second split of urea and M0P was applied at maximum tillering stage and the remaining split at panicle initiations stage.

3.9 Sowing and Transplanting

A well-puddled land was selected for the raising of seedlings. The sprouted seeds of rice were sown in the seedbed on 15 June 2007.Adequate care of the seedlings was taken. The 30 days old seedlings were uprooted carefully from the seedbed in the morning and transplanted on the same day. After satisfactory land preparation followed by layout of the experimental field, the rice seedling were transplanted in the plots on July15, 2007. Three seedlings were placed in each hill with a spacing of 15 cm× 20cm.

3.10 Intercultural operations

During growing period of the crop, all necessary cares were done for ensuring and maintaining the normal growth and development of the crop. The following intercultural operations were done.

3.10.1 Irrigation

The experiment was conducted during wet season and so, irrigation was not needed frequently. The plots were irrigated (3-4) times so as to maintain the requisite soil moisture for optimum growth of the plants. About 5-6 cm water height was maintained in the plots up to the milk stage of rice plant. Excess water was drained out when the grains reached hard dough stage.

3.10.2 Weeding

The experimental plots were infested with some common weeds, which were removed twice by uprooting.

3.10.3 Insect control

The field was infested by rice stem borer, which was controlled by spraying Furadan 3G on 25 July 2007.

3.11 Plant Sampling at Harvesting

Ten hills were randomly selected from each plot to record the yields contributing characters like plant height (cm) , number of tillers/hill , Panicle length (cm) ,number of grains/panicle, 1000 grain weight (g) and %filled grain . The selected hills were collected before harvesting.

3.12 Harvesting

The crop was harvested at maturity on 25th October 2007. The harvested crop was threshed plot wise. Grain and straw yield were recorded separately plot wise and expressed at t/ha on Sun-dry basis. Dry weight for both grain and straw were also recorded.

3.13 Data collection

The data on the following yields contributing characters of the crop were recorded as follows:

3.13.1 Plant height (cm)

The height of the plant in cm was measured from the ground level to the top of the panicle. From each plot, plants of ten hills were measured and averaged.

3.13.2 Number of Tillers/hill

Ten tillers were taken at random from each plot. The number of tillers/hill was counted. The numbers of effective tillers/hill were also determined

3.13.3 Panicle length (cm)

Panicle length in cm was measured from basal node of the rachis to apex of each panicle. Each observation was an average of 10 hills.

3.13.4 Number of grains per panicle

Ten panicle were taken at random and the unfilled and filled grain/ panicle were counted and averaged as well as % filled and % unfilled grain/panicle was counted.

3.13.5 1000-grain weight

The weight of 1000 grain from each plot was taken after sun drying by an electrical balance and expressed in g.

3.13.6 Grain Yield

After harvesting of the crop, grain yield from each unit plot was dried and weighed. The result was expressed as kg/ha on 14%moisture basis.

3.13.6 Straw yield

After harvesting the crop, straw yield from each unit plot was dried and weighted. The result was expressed as kg/ha.

3.14 Chemical analysis of soil sample

3.14.1 **Collection and preparation of soil samples**

Soil samples from the experimental field before the start of the experiment were collected from 10 different random spots from a depth of 0-15 cm. the soil samples were mixed thoroughly to make a composite sample and the unwanted materials such as stubbles, stones, weeds, etc. were removed from soil. The soil samples were air-dried, ground, and sieved through a 2-mm (10 mesh) sieve. The composite sample was stored in a clean container for physical and chemical analysis.

3.14.2 Analysis of soil sample

Soil samples were analyzed were both physical and chemical properties in the laboratory of the dept. of soil Science. SAU Dhaka .The properties studied included soil texture, pH, Organic matter, total N, available S and Zn content .The physical and chemical properties of initial soil have been presented in table 2. The soil was analyzed following standard method.

3.14.3 Mechanical analysis: Mechanical analysis was done by hydrometer method (Bouyoucos, 1927). The textural class was determined by plotting the values for % Sand, % silt and % clay to the "Marshall's Textural Triangular coordinate" following the USDA system .

3.14.4 Soil pH: Soil pH was measured with the help of a glass electrode pH meter, the soil-water ratio being 1:25. as described by Jackson (1962).

3.14.5 Organic matter content: Organic carbon in soil was determined by wet oxidation method of Walkley and Black (1934). The amount of organic matter was calculated by multiplying the percent organic carbon with the van Bemmelen factor, 1.73 (pipper, 1950) .The result was expressed in percentage.

3.14.6 Total nitrogen: Total N content of soil was determined by Kjeldahi method where the

soilsamplewasdigestedwith30%H_2O_2,conc.H_2SO_4andcatalystmixture(K_2SO_4:$CuSO_4.5H_2O$:Se powder in the ratio of 10:1:0.1). Nitrogen in the digest was determined by distillation with 40% NaOH followed by titration of the distillate trapped in H_3BO_3 with 0.01 N H_2SO_4 (Page *et al.*, 1982).

3.14.7 Available phosphorous: Available P content was extracted from soil with 0.5 M $NaHCO_3$ solution at a pH 8.5 (Olsen *et al.*, 1954). The P in the extract was then determined by developing blue color with $SnCl_2$ reduction of phosphgomolybdate complex and measuring the co lour by spectrometer at 660 nm wavelengths (Page *et al.*, 1982)

3.14.8 Exchangeable potassium: Exchangeable K was determined by extraction with 1 M NH_4OAc, pH 7.0 solution followed by measurement of extractable K by flam photometer and Ca and Mg by atomic absorption spectrophotometer (Black, 1965)

3.14.9 Available Sulphur: Available S content in soil was determined by extracting soil sample with $CaCl_2$ (0.15%) solution as described by Page *et al.* (1982). The S content in the extract was determined turbidimeterically and the turbid was measured by spectrometer at 420 nm wavelength.

3.14.10 Available zinc: Available Zn content in soil was determined by DTPA extraction method as described by Hunter (1984). The concentration of the element in the extract was estimated by atomic absorption spectrophotometer.

3.15 Chemical analysis of Plant samples

3.15.1 Preparation of plant sample

The plant samples were dried in an oven at 60°C for about 48 hours and then ground by a grinding machine. The ground plant materials were stored in paper bags in desiccators.

The grain and straw samples were analyzed for determination of N, S and Zn concentration. The methods were as follows:

3.15.2 Digestion of plant samples with nitric-perchloric acid

A sub-sample weighing 0.5 g was transferred into a dry, clean 100 ml kjeldahl flask. A 10 ml of diacid mixture (HNO_3:$HClO_4$ in the ratio 2:1) was added. After leaving for while, the flask was heated at a temperature slowly raised to 200°C. Heating was momentarily stopped when the dense white fumes of $HClO_4$ occurred. The contents of the flask were boiled until they became clean and colorless. Elements like P, K, S and Zn were determined from the digest.

3.15.3 Digestion of plant samples with sulphuric acid

An amount of 100 mg oven dry, ground samples was taken in a 100 ml Kjeldhal flask. Into the flask, 1.0 g catalyst mixture (K_2SO_4:$CuSO_4.5H_2O$:Se =10:1:0.1), 2 ml 30% H_2O_2 and 3ml conc. H_2SO_4 were added. The flask was swirled and allowed to stand for about 10 minutes, followed by heating at 200°C. Heating was continued until the digest was clear and colorless. After cooling, the contents were taken into a 100 ml volumetric flask and the volume was made with distilled water. This digestion was used for N determination exclusively.

3.16 Determination of elements

Nitrogen content: The N concentration in the digest was determined by distillation with 40% NaOH followed by titration of the distillate trapped in H_3BO_3 with 0.01N H_2SO_4 (Page *et al.*, 1982).

3.16.1 Sulphur content: The concentration in the digest was estimated turbid metrically by a spectrophotometer using 420 nm wavelength.

3.16.2 Zinc content: The Zn concentration in the digest was measured directly by an atomic absorption spectrophotometer.

3.17 Statistical analysis

The analysis of variance for various crop characters and also for nutrient concentration and uptake were done following the principle of F-statistics. Mean comparison of the treatments were adjudged by the Duncan's Multiple Range Test(Gomez and Gomez, 1984). Correlation statistics was performed top examine the interrelationship among the plant characters under study.

results and discussions

RESULTS AND DISCUSSION

The present experiment was conducted to determine the effect of different levels of sulphur and zinc on the yield and yields contributing characters of T-aman rice as well as the nutrient content and their uptake by grain and straw and also the content of nutrients in post harvest soil. Data on different characters were recorded and analyzed to find out the effects of sulphur and zinc on T-aman rice. The results have been presented and discussed, and possible interpretations are given under the following headings:

4.1 Yield and yield contributing character

Yield contributing characters such as plant height, number of effective tillers/hill , in-effective tillers/ hill, panicle length, number of filled grain/ panicles, number of unfilled grain/ panicle , weight of 1000 seeds, and grain and straw yield per hectare were recorded.

4.1.1 Plant height

Plant height differed significantly for the application of different level of sulphur in T-aman rice (Table 5). The maximum plant height (124.74 cm) was recorded in S_{20} treatment consisting of 20 kg S/ha which was statistically identical (122.29 cm and 120.30 cm) with S_{16} and S_{12} treatment as 16 kg and 12 kg S/ha, respectively, while the shortest plant (115.63 cm) was recorded in S_0 treatment i.e. control condition. Smith and Siregar (1983) reported that amino acids which containing sulphur is important in the synthesis of other compounds within the cell, such as S adenosyl methionine serves as a methyl donor in biosynthesis of many component including chlorophyll, flavonoids and sterols which help to optimum growth of plant.

Statistically significant difference was recorded for plant height due to the application of different levels of zinc (Table 5). The maximum plant height(125.35 cm) was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was statistically identical (120.61 cm) with Zn_1 treatment as of 1 kg Zn/ha and the minimum plant height (116.26 cm) was recorded in Zn_0 treatment i.e. control condition under the present trial (Table 4). With increasing level of zinc plant height also increases. Ullah *et al.* (2001) found that plant height increased with $ZnS0_4$ application.

Interaction effect also recorded between sulphur and zinc in consideration of plant height and found statistically significant (Table 6). The maximum plant (129.31 cm) was recorded in the treatment combination of $S_{16}Zn_2$ (16 kg S/ha + 2 kg Zn/ha), while the minimum plant height (110.84 cm) was recorded in the treatment combination of S_0Zn_0 i.e. without any sulphur and zinc (Table 6).Significant effect of S and Zn on plant height of rice has also been observed by many others in past (Subramanian , 1993 and Vaddin *et al., 1997)*

4.1.2 Number of effective tillers per hill

For the application of different levels of sulphur in T-aman rice showed significant variation on the number of effective tillers/hill varied (Table 5). The maximum number of effective tillers/hill (11.70) was observed in S_{20} treatment consisting of 20 kg S/ha which was closely followed (10.86) by S_{16} treatment as 16 kg S/ha, while the minimum number of effective tillers/ hill (10.15) was found in S_0 treatment i.e. control condition which was statistically identical (10.37) with S_{12} as 12 kg S/ha (Table 5).

Application of different levels of zinc on the number of effective tiller per plant differed significantly (Table 5). The maximum number of effective tillers per hill (11.17) was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was statistically similar (10.89) with Zn_1 treatment as of 1 kg Zn/ha and the minimum number of effective tillers per hill (10.24) was found in Zn_0 treatment . Ullah *et al.* (2001) found that tiller number increased with $ZnS0_4$ application.

Significant interaction effect was observed between sulphur and zinc in consideration of number of effective tillers per hill (Table 6). The maximum number of effective tiller per hill (12.40) was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the minimum number of effective tillers per hill (10.04) was recorded in the control treatment ($S_0Zn_{0)}$

4.1.3 Number of in effective tillers per plant

Number of in effective tillers per plant differed significantly due to the application of different levels of sulphur in T-aman rice (Table 5). The minimum number of in effective tillers per hill (1.27) was recorded in S_{20} treatment consisting of 20 kg S/ha which was statistically similar (1.39) with S_{16} treatment as 16 kg S/ha, while the maximum number of in effective tillers per hill (1.87) was recorded in S_0 treatment i.

Number of in effective tillers hill differed significantly due to the application of different levels of zinc (Table 5). The minimum number of non effective tiller per plant (1.40) was recorded from Zn_1 treatment (1 kg Zn/ha) which was statistically similar (1.51) with Zn_2 treatment (2 kg Zn/ha) and the maximum number of in effective tiller per hill (1.73) was recorded in Zn_0 treatment.

Interaction effect between S and Zn showed statistically significant differences for number of in effective tillers per hill due to the application of sulphur and zinc (Table 6). The minimum number of in effective tillers per hill (1.00) was recorded in the treatment combination of $S_{20}Zn_1$ (20 kg S/ha + 1 kg Zn/ha), while the maximum number of in effective tillers per hill (1.92) was recorded in the treatment combination of S_0Zn_1 i.e. without sulphur and 1 kg Zn/ha (Table 6).

4.1.4 Number of total tillers per hill

Different levels of sulphur in T-aman rice differed significantly for number of total tiller per hill (Table 5). With the increasing levels of S showed an increasing trend. The maximum number of total tillers per hill (12.97) was recorded in S_{20} treatment (20 kg S/ha) on the other hand the minimum number of total tillers per hill (12.01) was recorded in S_{12} treatment (12 kg S/ha) which was statistically identical (12.02 and 12.26) with S_0 and S_{16} (Table 5). Uddin *et al.* (1997) reported that during aman season application of 20 kg S/ha increased tillering of rice.

A statistically significant difference was recorded for number of total tiller per plant for the application of different levels of zinc (Table 5). The maximum number of total tillers per hill (12.69) was recorded in Zn_2 treatment (2 kg Zn/ha) and the minimum number of total tillers per hill (11.97) was recorded in Zn_0 treatment which was statistically similar (12.29) with Zn_1 treatment (1 kg Zn/ha) (Table 5). Ullah *et al.* (2001) found that tiller number increased with $ZnS0_4$ application.

A statistically significant difference was recorded for the interaction effect between sulphur and zinc in consideration of number of total tillers per hill (Table 6). The maximum number of total tillers per hill (13.52) was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the minimum number of total tillers per hill (11.64) was recorded in the treatment combination of $S_{12}Zn_0$ (Table 6).

4.1.5 Panicle length

Panicle length differed significantly due to the application of different level s of sulphur in T-aman rice (Table 5). The maximum panicle length (28.50 cm) was recorded in S_{20} treatment consisting of 20 kg S/ha which was statistically identical (27.20 cm and 26.78 cm) with S_{16} and S_{12} treatment as 16 kg and 12 kg S/ha, respectively, while the minimum panicle length (25.89 cm) was recorded in S_0 treatment i.e. control condition (Table 5).

Statistically significant difference was recorded for panicle length due to the application of different levels of zinc (Table 5). The maximum panicle length (27.98 cm) was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was statistically identical (27.28 cm) with Zn_1 treatment (1 kg Zn/ha) and the shortest panicle length (26.01 cm) was recorded in Zn_0 treatment . Increasing levels of zinc showed increasing panicle length.

Interaction effect between sulphur and zinc on panicle length was found statistically significant (Table 6). The longest panicle length (29.49 cm) was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the minimum panicle length (24.59 cm) was recorded in the treatment combination of S_0Zn_0 i.e. without sulphur and zinc (Table 6).

4.1.6 Number of filled grains per panicle

Number of filled grains per panicle varied significantly due to the application of different levels of sulphur in T-aman rice (Table 5). The maximum number of filled grains per panicle (68.56) were recorded in S_{20} treatment (20 kg S/ha) which was statistically identical (66.37 and 65.46) with S_{16} and S_{12} treatments (16 kg and 12 kg S/ha, respectively,) while the minimum number of filled grains per panicle (59.68) was recorded in S_0 treatment i.e. control condition (Table 5).

A statistically significant difference was recorded due to the application of different levels on the zinc for number of filled grains per panicle (Table5). The maximum number of filled grains per panicle (67.42) was recorded in Zn_2 treatment (2 kg Zn/ha) which was statistically identical (66.88) with Zn_1 treatment (1 kg Zn/ha) and the minimum number of filled grains per panicle (60.74) was recorded in Zn_0 treatment.

Interaction effect between sulphur and zinc on the number of filled grains per panicle was found statistically significant (Table 6). The maximum number of filled grains per panicle (72.05) was recorded from the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the minimum number of filled grains per panicle (54.08) was recorded in the treatment combination of S_0Zn_0 i.e. without any sulphur and zinc (Table 6).

4.1.7 Number of unfilled grains per panicle

Different levels of sulphur in T-aman rice for number of unfilled grains per panicle differed significantly (Table 5). The minimum number of unfilled grains per panicle (11.22) was recorded in S_{20} treatment (20 kg S/ha) which was closely followed (13.76) by

S_{16} treatment (16 kg S/ha), while the maximum number of unfilled grains per panicle (15.18) was recorded in S_0 treatment.

Statistically significant difference was recorded on the number of unfilled grains per panicle due to the application of different levels of zinc (Table 5). The minimum number of unfilled grains per panicle (13.19) was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was statistically identical (13.54) with Zn_1 treatment (1 kg Zn/ha) and the maximum number of unfilled grains per panicle (14.25) was recorded in Zn_0 treatment

In consideration of number of unfilled grains per panicle a statistically significant interaction effect was recorded between sulphur and zinc (Table 6). The minimum number of unfilled grains per panicle (10.50) was observed in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the maximum number of unfilled grains per panicle (15.42) was recorded in the treatment combination of S_0Zn_0 i.e. control treatment

4.1.8 Number of total grains per panicle

The Number of total grains per panicle differed significantly due to the application of different levels of sulphur in T-aman rice (Table 5). The maximum number of totals grain per panicle (80.13) was recorded in S_{16} treatment consisting of 16 kg S/ha which was statistically identical (78.94 and 79.94) with S_{12} and S_{20} treatment (12 kg and 20 kg S/ha, respectively,) while the minimum number of total grains per panicle (74.86) was recorded in S_0 treatment. Uddin *et al.* (1997) reported that during aman season application of 20 kg S/ha increased grains per panicle of rice.

Statistically significant variation was recorded on the number of total grains per panicle due to the application of different levels of zinc under the trial (table 5). The maximum number of total grains per panicle (80.61) was recorded in Zn_2 treatment (2 kg Zn/ha) which was statistically identical (80.43) with Zn_1 treatment (1 kg Zn/ha) and the minimum number of total grains per panicle (74.99) was recorded in Zn_0 treatment

Interaction effect was recorded between sulphur and zinc in consideration of number of total grains per panicle and found statistically significant (Table 6). The maximum number of total grains per panicle (82.55) was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the minimum number of total grains per panicle (69.50) was recorded in the treatment combination of S_0Zn_0 i.e. without any sulphur and zinc (Table 6).

4.1.9 Weight of 1000 seeds

Weight of 1000 seeds showed statistically non significant variation due to the application of different levels of sulphur in T-aman rice (Table 5). The highest weight of 1000 seeds (21.96 g) was recorded in S_{20} treatment consisting of 20 kg S/ha, while the lowest weight of 1000 seeds (20.96 g) was recorded in control treatment. (Table 5). Sarfaraz *et al.* (2002) reported that S fertilizers at 20 kg ha^{-1} 1000-grain weight were significantly increased with the application of S fertilizer compared to the control.

A statistically non significant variation was recorded for weight of 1000 seeds due to the application of different levels of zinc (Table5). The highest weight of 1000 seeds (21.46 g) was recorded in Zn_2 treatment (2 kg Zn/ha) and the lowest weight of 1000 seeds (21.30g) was recorded in Zn_0. Ullah *et a*l. (2001) found that 1000-grain weight increased with $ZnS0_4$ application.

Interaction effect showed statistically non significant differences between sulphur and zinc in consideration of weight of 1000 seeds (Table 6). The highest weight of 1000 seeds (21.87 g) was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest weight of 1000 seeds (20.80 g) was recorded in the treatment combination of S_0Zn_0 i.e. without any Sulphur and zinc (Table 6).

4.1.10 Grain yield

Grain yield varied significantly for different levels of Sulphur in T-aman rice (Table 5). The highest grain yield (3.88 t/ha) was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (3.63 and 3.56 t/ha) by S_{16} and S_{12} treatment as 16 kg and 12 kg S/ha, respectively, while the lowest grain yield (3.34 t/ha) was recorded in S_0 treatment i.e. control condition (Figure 1). Mukhopadhyay *et al.* (1995) found that gypsum and pyrite were equally effective in increasing rice yield when applied at the rate of 20 kg S/ha. Sarkunan *et al.* (1998) reported that S at 25 g kg^{-1} resulted in 9% increase in grain yield. Biswas *et al.* (2004) reported that the optimum S rate varied between 30-45 kg ha^{-1} and rice yields increased from 5 to 51%.

A statistically significant variation was recorded for grain yield due to the application of different levels of zinc (Table 5). The highest grain yield (3.77 t/ha) was recorded from Zn_2 treatment comprising of 2 kg Zn/ha which was closely followed (3.64 t/ha) with

Zn_1 treatment (1 kg Zn/ha) and the lowest grain yield (3.40 t/ha) was recorded in Zn_0 treatment With increasing levels of zinc grain yield also increases. Arifet *et al.* (1996) reported that the yield of grain was greatest with 10 kg Zn ha^{-1}. Atra and Poi (1998) reported that the best result (grain yield 2.39 t/ha) was obtained with foliar application of

500g chelated Zn ha^{-1}.

Interaction effect between sulphur and zinc on the grain yield of T-Aman was found statistically significant. (Fig.3 and tab.6). The highest grain yield (4.20 t/ha) was recorded from the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest grain yield (3.01 t/ha) was recorded in the treatment combination of S_0Zn_0 i.e. without any sulphur and zinc. Idris and Jahiruddin (1982) reported that the maximum yield of 4900 kg ha^{-1} (10% increase over control) was recorded due to combined application of Zn and S. Khan *et al.* (1991) reported that application of gypsum (160 kg gypsum ha^{-1}) +Zn (5 kg Zn ha^{-1}) produced the highest yields of rice.

4.1.11 Straw yield (t/ha)

Different levels of sulphur in T-aman rice for straw yield differed significantly (Fig.4 and Tab.5). The highest straw yield (5.32 t/ha) was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (4.98 and 4.88 t/ha) by S_{16} and S_{12} treatment (16 kg and 12 kg S/ha, respectively,) while the lowest straw yield (4.72 t/ha) was recorded in S_0 treatment.

Statistically significant difference was recorded due to the application of different levels of zinc on straw yield of T-Aman (Fig.5 and Tab.5). The highest straw yield (5.13 t/ha) was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was closely followed (5.01 t/ha) with Zn_1 treatment as of 1 kg Zn/ha and the lowest straw yield (4.78 t/ha) was recorded in Zn_0 treatment i.e. control condition under the present trial (Figure 5). With increasing level of zinc straw yield also increases. Ullah et al. (2001) found that straw yields increased with $Zn5O_4$ application.

Table 5 Individual effect of sulphur and zinc on the yield contributing characters and yields of T-aman rice

Levels of S and Zn	Plant height (cm)	Number of effective tillers per hill	Number of in effective tillers per hill	Number of total tillers per hill	Panicle length (cm)	Number of filled grains per panicle	Number of unfilled grains per panicle	Number of total grainsper panicle	Weight of 1000 seeds (g)	Grain yield (t/ha)	Straw yield (t/ha)
Sulphur											
S_0	115.63 b	10.15 c	**1.87 a**	12.02 b	25.89 b	59.68 b	**15.18 a**	74.86 b	20.95	3.34 c	4.72 c
S_{12}	120.30 ab	10.37 c	1.65 b	12.01 b	26.78 ab	65.46 a	14.48 ab	79.94 a	21.03	3.56 b	4.88 b
S_{16}	122.29 ab	10.86 b	1.39 c	12.26 b	27.20 ab	66.37 a	13.76 b	**80.13 a**	21.58	3.63 b	4.98 b
S_{20}	**124.74 a**	**11.70 a**	1.27 c	**12.97 a**	**28.50 a**	**68.56 a**	11.22 c	79.78 a	**21.96**	**3.88 a**	**5.32 a**
$LSD_{(0.05)}$	6.469	0.371	0.178	0.379	1.640	3.064	0.817	2.942	--	0.103	0.135
Significance level	0.05	0.01	0.01	0.01	0.05	0.01	0.01	0.01	NS	0.01	0.01
Zinc											
Zn_0	116.26 b	10.24 b	**1.73 a**	11.97 b	26.01 b	60.74 b	**14.25 a**	74.99 b	21.30	3.40 c	4.78 c
Zn_1	120.61 ab	10.89 a	1.40 b	12.29 b	27.28 ab	66.88 a	13.54 ab	80.43 a	21.38	3.64 b	5.01 b
Zn_2	**125.35 a**	**11.17 a**	1.51 b	**12.69 a**	**27.98 a**	**67.42 a**	13.19 b	**80.61 a**	**21.46**	**3.77 a**	**5.13 a**
$LSD_{(0.05)}$	5.602	0.321	0.154	0.328	1.421	2.653	0.707	2.548	--	0.089	0.117
Significance level	0.01	0.05	0.01	0.01	0.05	0.01	0.05	0.01	NS	0.01	0.01

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

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

Sulphur × Zinc	Plant height (cm)	Number of effective tillers per hill	Number of in effective tillers per hill	Number of total tillers per hill	Panicle length (cm)	Number of filled grains per panicle	Number of unfilled grains per panicle	Number of total grains per panicle	Weight of 1000 seeds (g)	Grain yield (t/ha)	Straw yield (t/ha)
S_0Zn_0	110.84 c	10.04 e	1.82 abc	11.86 de	24.59 c	54.08 c	**15.42 a**	69.50 c	20.80	3.01 e	4.50 e
S_0Zn_1	115.27 bc	10.15 e	**1.92 a**	12.07 cde	26.26 abc	62.58 b	15.11 a	77.69 ab	20.91	3.49 d	4.80 d
S_0Zn_2	120.76 abc	10.25 de	1.87 ab	12.12 cde	26.81 abc	62.38 b	15.00 ab	77.38 ab	21.15	3.53 d	4.86 cd
$S_{12}Zn_0$	118.85 abc	10.08 e	1.56 bc	11.64 e	25.81 bc	62.42 b	14.80 ab	77.22 ab	21.00	3.51 d	4.82 d
$S_{12}Zn_1$	119.67 abc	10.48 de	1.49 c	11.97 cde	27.04 abc	66.95 ab	14.50 abc	81.45 ab	20.81	3.57 cd	4.88 cd
$S_{12}Zn_2$	122.36 abc	10.53 de	1.89 ab	12.42 bcd	27.48 abc	67.00 ab	14.15 abc	81.15 ab	21.27	3.61 cd	4.93 cd
$S_{16}Zn_0$	115.44 bc	10.17 e	1.82 abc	12.00 cde	26.36 abc	62.97 b	14.67 ab	77.63 ab	21.48	3.53 d	4.84 d
$S_{16}Zn_1$	122.11 abc	10.92 cd	1.18 d	12.10 cde	27.09 abc	67.90 ab	13.50 bcd	81.40 ab	21.70	3.62 cd	4.97 cd
$S_{16}Zn_2$	**129.31 a**	11.50 bc	1.18 d	12.68 bc	28.15 ab	68.25 ab	13.10 cd	81.35 ab	21.55	3.75 bc	5.12 c
$S_{20}Zn_0$	119.89 abc	10.68 de	1.70 abc	12.38 bcde	27.29 abc	63.52 b	12.10 de	75.62 b	21.90	3.55 d	4.95 cd
$S_{20}Zn_1$	125.38 ab	12.02 ab	1.00 d	13.02 ab	28.72 ab	70.10 a	11.07 ef	81.17 ab	22.10	3.90 b	5.38 b
$S_{20}Zn_2$	128.97 a	**12.40 a**	1.12 d	**13.52 a**	**29.49 a**	**72.05 a**	10.50 f	**82.55 a**	**21.87**	**4.20 a**	**5.62 a**
$LSD_{(0.05)}$	11.20	0.643	0.308	0.656	2.841	5.306	1.415	5.096	--	0.178	0.233
Significance level	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	NS	0.01	0.01
CV(%)	5.48	8.53	11.82	7.14	6.19	9.82	6.12	7.83	5.94	7.89	5.74

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

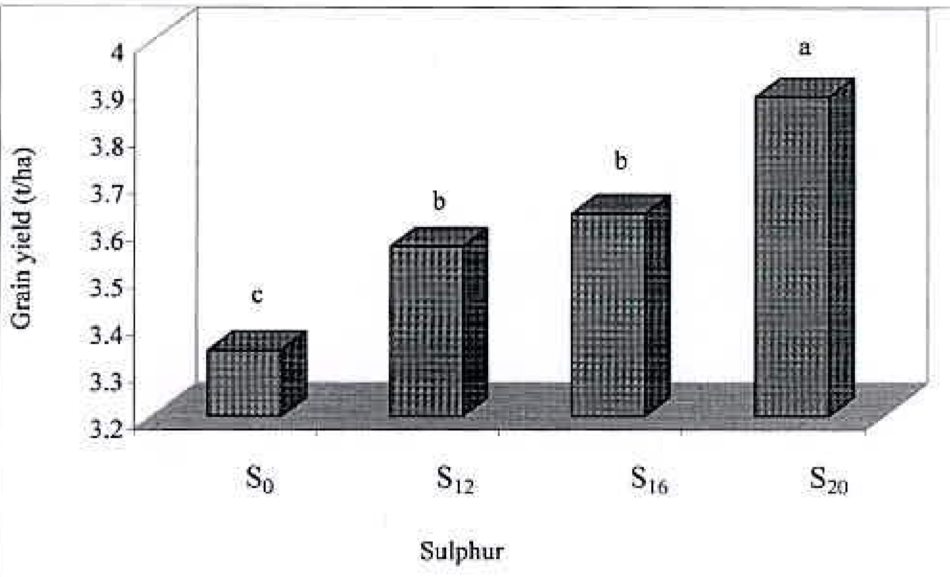

Figure 1. Effect of sulphur on grain yield of T-aman rice

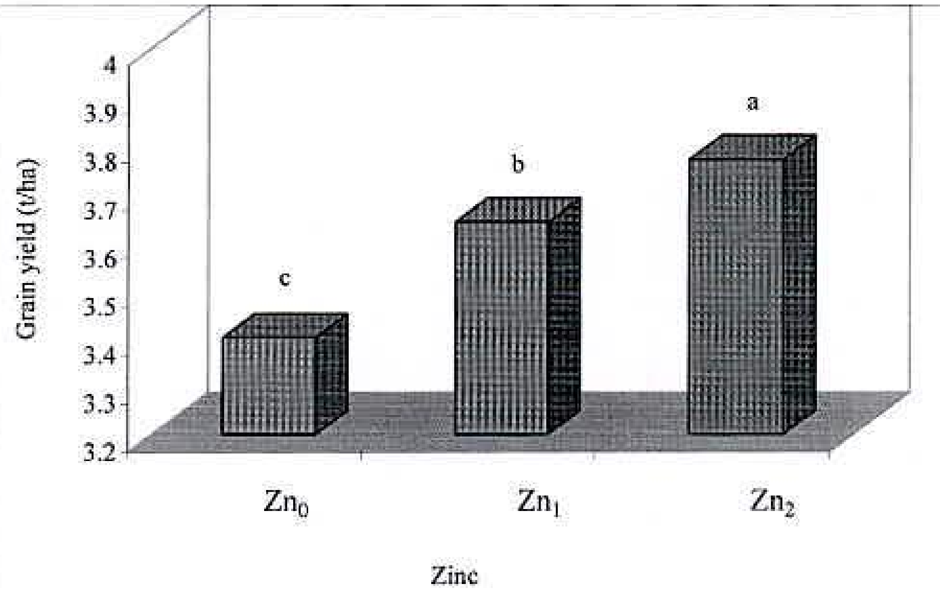

Figure 2. Effect of zinc on grain yield of T-aman rice

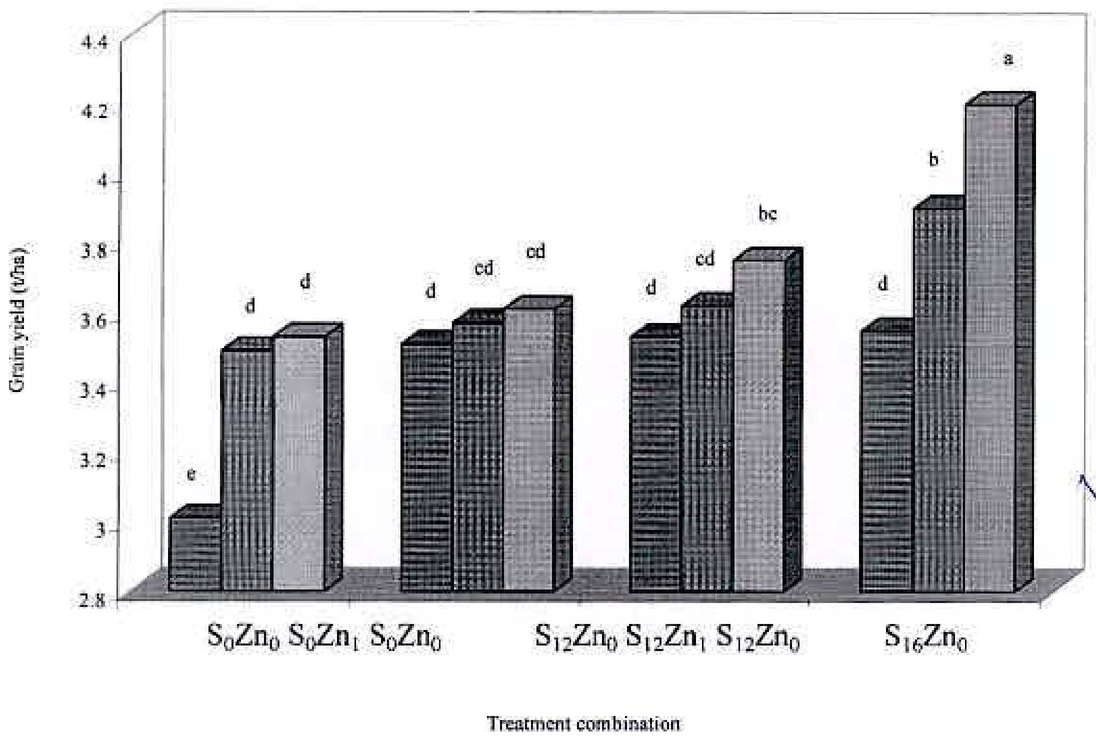

Figure 3. Interaction effect of sulphur and zinc on the grain yield of T-aman rice

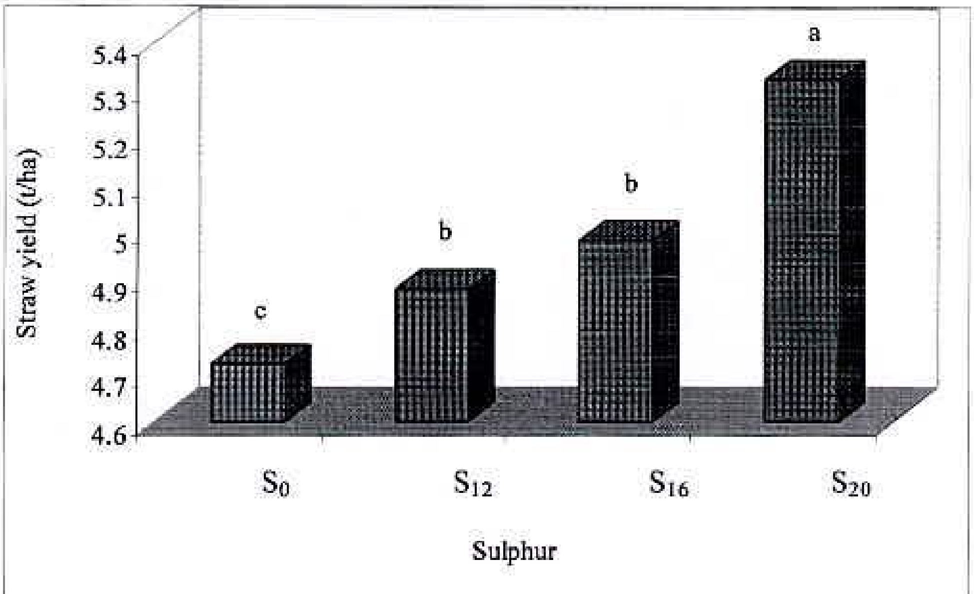

Figure 4. Effect of sulphur on straw yield of T-aman rice

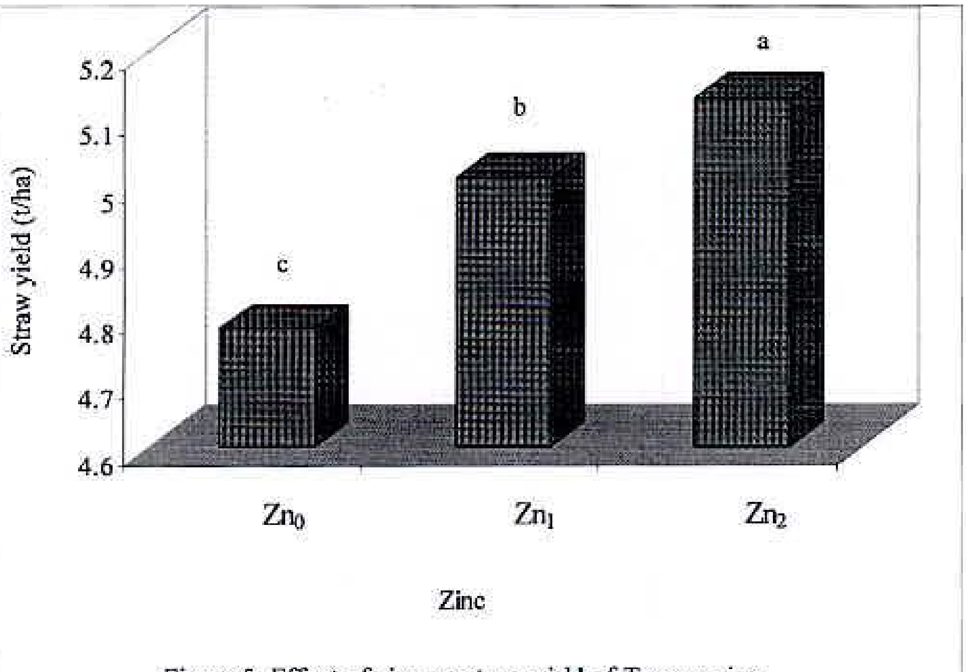

Figure 5. Effect of zinc on straw yield of T-aman rice

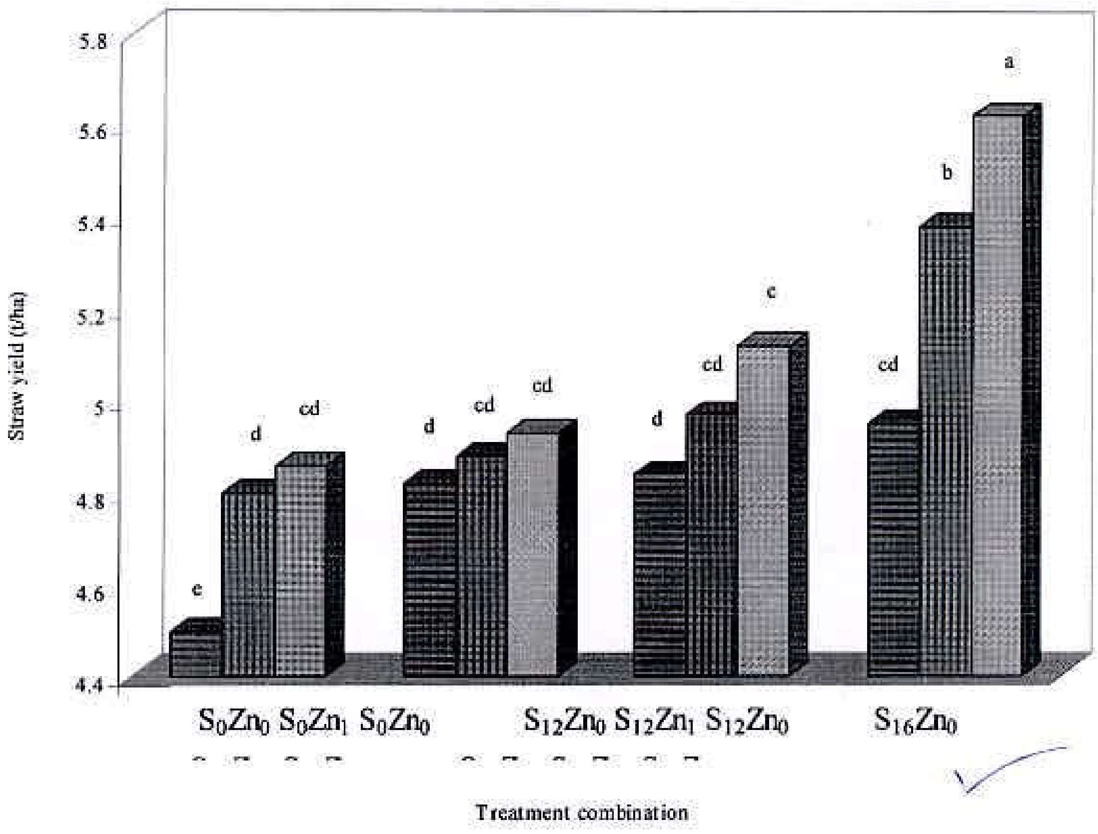

Figure 6. Interaction effect of sulphur and zinc on straw yield of T-aman rice

Interaction effect also showed statistically significant differences between Sulphur and zinc in consideration of straw yield (Appendix II). The highest straw yield (5.62 t/ha) was recorded from the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest straw yield (4.50 t/ha) was recorded from the treatment combination of S_0Zn_0 i.e. without sulphur and zinc (Figure 6).

4.2 S concentrations in grain, straw, and post harvest soil

Concentration of S was determined from the grain and straw samples, uptake of S by grain and straw and S in post harvest soil.

4.2.1 S concentration in grain

Concentration of S in grain showed statistically significant difference due to the application of different levels of sulphur in T-aman rice (Tab.7). The highest (0.086%) concentration of S in grain was recorded in S_{20} treatment consisting of 20 kg S/ha which was statistically identical (0.077%) with S_{16} (16 Kg S/ha) and the lowest (0.052%) concentration of S in grain was recorded in S_0 treatment (Table 7).

Statistically significant variation was recorded for concentration of S in grain due to the application of different levels of zinc (Table 7). The highest (0.073%) concentration of Zn in grain was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was closely followed (0.072%) by Zn_1 treatment (1 kg Zn/ha) and the lowest (0.069%) concentration of Zn in grain was recorded from Zn_0 treatment (Table 7).

Interaction effect between sulphur and zinc on the S concentration in grain was found statistically significant (Table 8). The highest (0.089%) concentration of S in grain was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (0.051%) concentration of S in grain was recorded in the treatment combination of S_0Zn_0 i.e. without any sulphur and zinc (Table 8).

4.2.2 S concentration in straw

The application of different levels of sulphur in T-aman rice showed significance variation on the concentration of S in straw. (Table7). The highest (0.151%) concentration of S in straw was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (0.120%) by S_{16} as 16 kg and the lowest (0.085%) concentration of S in straw was recorded in S_0 treatment (Table 7).

Statistically significant variation was recorded due to the the application of different levels of zinc on concentration of S in straw (Table 7). The highest (0.119%) concentration of S in straw was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was closely followed (0.112%) by Zn_0 treatment and the lowest (0.109%) concentration of S in straw was recorded in Zn_1 treatment (1 kg Zn/ha)(Table 7).

Statistically significant difference was recorded for interaction effect between sulphur and zinc on the concentration of S in straw (Table 8). The highest (0.166%) concentration of S in straw was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (0.083%) concentration of S in straw was recorded in the treatment combination of S_0Zn_0 i.e. control condition (Table 8).

4.2.3 S uptake by grain

Statistically significant difference was recorded for the uptake of S by grain due to the application of different levels of sulphur in T-aman rice (Table 7). The highest (3.39 kg/ha) uptake of S by grain was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (2.88 kg/ha) by S_{16} as 16 kg and the lowest (1.74 kg/ha) uptake of S by grain was recorded in S_0 treatment (Table 7).

A statistically significant difference was recorded for uptake of S by grain due to the application of different levels of zinc (Table 7). The highest (2.84 kg/ha) uptake of S by grain was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was closely followed (2.64 kg/ha) by Zn_1 treatment (1 kg Zn/ha) and the lowest (2.43 kg/ha) uptake of S by grain was recorded in Zn_0 treatment (Table 7).

Statistically significant difference was recorded due to the interaction effect of sulphur and zinc in consideration of S uptake by grain (Table 8). The highest (3.73 kg/ha) uptake of S by grain was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (1.53 kg/ha) uptake of S by grain was recorded in the treatment combination of S_0Zn_0 i.e. without any sulphur and zinc (Table 8).

4.2.4 S uptake by straw

Uptake of S by straw performed statistically significant variation due to the application of different levels of sulphur in T-aman rice (Table 7). The highest (8.05 kg/ha) uptake of S by straw was recorded in S_{20} treatment (20 kg S/ha) which was closely followed (5.97 kg/ha) by S_{16} (16 kg S/ha) and the lowest (3.99 kg/ha) uptake of S by straw was recorded in S_0 treatment (Table 7).

Statistically significant differences were observed for the uptake of S by straw on the application of different levels of zinc (Table 7). The highest (6.18 kg/ha) uptake of S by straw was recorded in Zn_2 treatment (2 kg Zn/ha) and the lowest (5.39 kg/ha) uptake of S by straw was recorded in Zn_0 treatment i.e. control condition which was statistically similar (5.51 kg/ha) with Zn_1 treatment (1 kg Zn/ha) (Table 7).

Interaction effect recorded between sulphur and zinc for S uptake by straw was found statistically significant differences (Table 8). The highest (9.32 kg/ha) uptake of S by straw was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (3.73 kg/ha) uptake of S by straw was recorded in the treatment combination of S_0Zn_0 i.e. control condition (Table 8).

4.2.5 Total S uptake

The application of different levels of sulphur in T-aman rice on total S uptake showed statistically significant differences (Table 7). The highest (11.44 kg/ha) total uptake of S was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (8.85 kg/ha) by S_{16} (16 kg S/ha) and the lowest (5.73 kg/ha) total uptake of S was recorded in S_0 treatment (Table 7).

Total uptake of S due to the application of different levels of zinc showed a statistically significant difference (Table 7). The highest (9.02 kg/ha) total uptake of S was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was closely followed (8.14 kg/ha) by Zn_1 (1 kg Zn/ha) and the lowest (7.82 kg/ha) total uptake of S was recorded in Zn_0 treatment .

Interaction effect between sulphur and zinc in consideration of total S uptake showed statistically significant differences (Table 8). The highest (13.05 kg/ha) total uptake of S was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (5.26 kg/ha) total uptake of S was recorded in the treatment combination of S_0Zn_0 i.e. control condition (Table 8).

4.2.6 S in post harvest soil

A statistically significant variation was recorded for S in post harvest soil due to the application of different levels of sulphur in T-aman rice (Tab. 7). The highest (20.71 ppm) S in post harvest soil was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (18.76 ppm) by S_{16} as 16 kg and the lowest (12.65 ppm) S in post harvest soil was recorded in S_0 treatment (Table 7).

S in post harvest soil due to the application of different levels of zinc showed statistically significant variation (Table 7). The highest (17.74 ppm) S in post harvest soil was recorded in Zn_2 treatment (2 kg Zn/ha) which was closely followed (17.38 ppm) by Zn_1 (1 kg Zn/ha) and the lowest (16.92 ppm) S in post harvest soil was recorded in Zn_0 treatment.

Interaction effect also recorded between sulphur and zinc in consideration of S in post harvest soil was found statistically significant (Tab. 8). The highest (21.05 ppm) S in post harvest soil was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (12.33 ppm) S in post harvest soil was recorded in the treatment combination of S_0Zn_0 i.e. control condition (Table 8).

0 g soil) by S_{12} (Table 12).

Table 7 Individual effect of sulphur and zinc on sulphur concentration and uptake by grain , straw and post harvest soil of T-aman rice

Levels of S and Zn	S concentration in grain (%)	S concentration in straw (%)	S uptake by grain (kg/ha)	S uptake by straw (kg/ha)	Total S uptake (kg/ha)	S in post harvest soil (ppm)
Sulphur						
S_0	0.052 c	0.085 d	1.74 d	3.99 d	5.73 d	12.65 d
S_{12}	0.071 b	0.098 c	2.53 c	4.76 c	7.29 c	17.27 c
S_{16}	0.077 ab	0.120 b	2.88 b	5.97 b	8.85 b	18.76 b
S_{20}	**0.086 a**	**0.151 a**	**3.39 a**	**8.05 a**	**11.44 a**	**20.71 a**
$LSD_{(0.05)}$	0.009	0.009	0.103	0.207	0.205	0.107
Significance level	0.01	0.01	0.01	0.01	0.01	0.01
Zinc						
Zn_0	0.069 c	0.112 ab	2.43 c	5.39 b	7.82 c	16.92 c
Zn_1	0.072 b	0.109 b	2.64 b	5.51 b	8.14 b	17.38 b
Zn_2	**0.073 a**	**0.119 a**	**2.84 a**	**6.18 a**	**9.02 a**	**17.74 a**
$LSD_{(0.05)}$	0.008	0.008	0.089	0.180	0.178	0.186
Significance level	0.01	0.01	0.01	0.01	0.01	0.01

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

Table 8. Interaction effect of Sulphur and zinc on Sulphur concentration and uptake by grain , straw and post harvest soil of T-aman rice

Sulphur × Zinc	S concentration in grain (%)	S concentration in straw (%)	S uptake by grain (kg/ha)	S uptake by straw (kg/ha)	Total S uptake (kg/ha)	S in post harvest soil (ppm)
S_0Zn_0	0.051 c	0.083 e	1.53 h	3.73 g	5.26 i	12.33 j
S_0Zn_1	0.052 c	0.085 e	1.81 g	4.08 fg	5.89 h	12.68 i
S_0Zn_2	0.053 c	0.086 e	1.87 g	4.17 f	6.04 h	12.95 h
$S_{12}Zn_0$	0.068 bc	0.098 e	2.42 f	4.72 e	7.14 g	16.72 g
$S_{12}Zn_1$	0.071 ab	0.096 e	2.53 ef	4.68 e	7.21 fg	17.20 f
$S_{12}Zn_2$	0.074 ab	0.099 e	2.65 de	4.88 e	7.53 f	17.90 e
$S_{16}Zn_0$	0.076 ab	0.120 d	2.71 de	5.80 d	8.51 e	18.54 d
$S_{16}Zn_1$	0.077 ab	0.116 d	2.82 d	5.76 d	8.58 e	18.67 d
$S_{16}Zn_2$	0.078 ab	0.124 cd	3.11 c	6.34 c	9.45 d	19.07 c
$S_{20}Zn_0$	0.083 ab	0.148 b	3.05 c	7.32 b	10.37 c	20.11 b
$S_{20}Zn_1$	0.086 ab	0.139 bc	3.39 b	7.50 b	10.89 b	20.97 a
$S_{20}Zn_2$	**0.089 a**	**0.166 a**	**3.73 a**	**9.32 a**	**13.05 a**	**21.05 a**
$LSD_{(0.05)}$	0.017	0.0169	0.178	0.359	0.355	0.186
Significance level	0.01	0.01	0.05	0.01	0.01	0.01
CV(%)	2.80	3.11	4.03	3.72	2.51	2.63

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

4.3 Zn in grain, straw, and post harvest soil

Concentration of Zn was estimated from the grain and straw sample, uptake by grain and straw and Zn in post harvest soil was measured.

4.3.1 Zn concentration in grain

Concentration of Zn in grain showed statistically non significant difference due to the application of different levels of sulphur in T-aman rice (Tab. 9). The highest (29.53%) concentration of Zn in grain was recorded in S_{20} treatment consisting of 20 kg S/ha which was statistically similar (29.11% and 29.03%) by with S_{16} and S_{12} (16 kg and 12 kg S/ha) and the lowest (26.45%) concentration of Zn in grain was recorded in S_0 treatment (Table 9).

Statistically significant variation was recorded for concentration of Zn in grain for the application of different levels of zinc (Table 9). The highest (31.29%) concentration of Zn in grain was recorded in Zn_2 treatment (2 kg Zn/ha) which was closely followed (28.98%) by Zn_1 (1 kg Zn/ha) and the lowest (25.33%) concentration of Zn in grain was recorded in Zn_0 treatment (Table 9). Ullah *et al.* (2001) found that Zn content in grain increased with $ZnSO_4$ application.

Interaction effect between sulphur and zinc in consideration of Zn concentration in grain performed statistically significant differences (Tab. 10). The highest (32.00%) concentration of Zn in grain was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (19.90%) concentration of Zn in grain was recorded in the treatment combination of S_0Zn_0 (Table 10).

4.3.2 Zn concentration in straw

Concentration of Zn in straw showed statistically significant variation for the application of different levels of sulphur in T-aman rice (Tab. 9) The highest (16.81%) concentration of Zn in straw was recorded in S_{16} treatment consisting of 16 kg S/ha which was closely followed (16.61%) by S_{20} and the lowest (14.85%) concentration of Zn in straw was recorded in S_0 treatment which was closely followed (14.41%) by S_{12} (12 kg Zn/ha) (Table 9).

Concentration of Zn in straw for the application of different levels of zinc showed a statistically significant variation (Tab. 9). The highest (17.59%) concentration of Zn in straw was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was closely followed (16.30%) by Zn_1 (1 kg Zn/ha), while the lowest (13.12%) concentration of Zn in straw was recorded in Zn_0 treatment (Table 9). Ullah *et al.* (2001) found that Zn content in straw increased with $ZnS0_4$ application.

Interaction effect between sulphur and zinc in consideration of Zn concentration in straw showed statistically significant differences (Tab. 10). The highest (18.00%) concentration of Zn in straw was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (11.05%) concentration of Zn in straw was recorded in the treatment combination of S_0Zn_0 i.e. control treatment (Table 10).

4.3.3 Zn uptake by grain

Uptake of Zn by grain showed statistically significant difference due to the application of different levels of sulphur in T-aman rice (Tab. 9). The highest (0.115 kg/ha) uptake of Zn by grain was recorded in S_{20} treatment consisting of 20 kg S/ha which was statistically similar (0.106 kg/ha) with S_{16} (16 kg S/ha) and the lowest (0.089 kg/ha) uptake of Zn by grain was recorded in S_0 treatment which was closely followed (0.104 kg/ha) by S_{12} (12 kg S/ha) (Tab. 9).

A statistically significant difference was recorded for uptake of Zn by grain due to the application of different levels of zinc (Tab. 9). The highest (0.118 kg/ha) uptake of Zn by grain was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was closely followed (0.106 kg/ha) with Zn_1 treatment as of 1 kg Zn/ha and the lowest (0.087 kg/ha) uptake of Zn by grain was recorded from Zn_0 treatment (Table 9).

Interaction effect between sulphur and zinc in consideration of Zn uptake by grain was observed statistically significant (Tab. 10). The highest (0.134 kg/ha) uptake of Zn by grain was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (0.060 kg/ha) uptake of Zn by grain was recorded in the treatment combination of S_0Zn_0 i.e. without sulphur and zinc (Table 10).

4.3.4 Zn uptake by straw

Uptake of Zn by straw performed statistically significant difference for the application of different levels of sulphur in T-aman rice (Tab. 9). The highest (0.089 kg/ha) uptake of Zn by straw was recorded in S_{20} treatment (20 kg S/ha) which was statistically similar (0.084 kg/ha) with S_{16} and the lowest (0.070 kg/ha) uptake of Zn by straw was recorded in S_{12} (12 kg S/ha) which was statistically identical (0.071 kg/ha) with S_0 treatment (Table 9).

Uptake of Zn by straw due to the application of different levels of zinc showed a statistically significant variation (Tab. 9). The highest (0.090 kg/ha) uptake of Zn by straw was recorded inZn_2 treatment (2 kg Zn/ha) which was statistically similar (0.082 kg/ha) with Zn_1 treatment (1 kg Zn/ha) and the lowest (0.063 kg/ha) uptake of Zn by straw was recorded in Zn_0 treatment. (Table 9).

Interaction effect between sulphur and zinc in consideration of Zn uptake by straw showed statistically significant differences (Tab. 10). The highest (0.101 kg/ha) uptake of Zn by straw was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (0.050 kg/ha) uptake of Zn by straw was recorded in the treatment combination of S_0Zn_0 i.e. control treatment (Table 10).

4.3.5 Total Zn uptake

Statistically significant difference was recorded due to the application of different levels of sulphur in T-aman rice for total Zn uptake (Tab. 9). The highest (0.204 kg/ha) total uptake of Zn was recorded in S_{20} treatment (20 kg S/ha) which was closely followed (0.190 kg/ha) by S_{16} and the lowest (0.160 kg/ha) total uptake of Zn was recorded in S_0 treatment which was closely followed (0.174) by S_{12} (Table 10).

A statistically significant variation was recorded for total uptake of Zn due to the application of different levels of zinc (Tab. 9). The highest (0.208 kg/ha) total uptake of Zn was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was closely followed (0.188 kg/ha) by Zn_1 (1 kg Zn/ha) and the lowest (0.150 kg/ha) total uptake of Zn was recorded in Zn_0 treatment (Tab. 10)

Interaction effect between sulphur and zinc in consideration of total Zn uptake showed statistically significant differences (Appendix VII). The highest (0.235 kg/ha) total uptake of Zn was recorded from the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha),

Table 9. Effect of sulphur and zinc on zinc concentration and uptake by grain and straw, post harvest soil of T-aman rice

Levels of S and Zn	Zn concentration in grain (%)	Zn concentration in straw (%)	Zn uptake by grain (kg/ha)	Zn uptake by straw (kg/ha)	Total Zn uptake (kg/ha)	Zn in post harvest soil (ppm)
Sulphur						
S_0	26.45 b	14.85 c	0.089 c	0.071 b	0.160 d	0.97 b
S_{12}	29.03 a	14.41 d	0.104 b	0.070 b	0.174 c	1.12 a
S_{16}	29.11 a	**16.81 a**	0.106 ab	0.084 a	0.190 b	**1.14 a**
S_{20}	**29.53 a**	16.61 b	**0.115 a**	**0.089 a**	**0.204 a**	1.13 a
$LSD_{(0.05)}$	0.596	0.145	0.009	0.009	0.009	0.044
Significance level	0.01	0.01	0.01	0.01	0.01	0.01
Zinc						
Zn_0	25.33 c	13.12 c	0.087 c	0.063 b	0.150 c	0.82 c
Zn_1	28.98 b	16.30 b	0.106 b	0.082 a	0.188 b	1.13 b
Zn_2	**31.29 a**	**17.59 a**	**0.118 a**	**0.090 a**	**0.208 a**	**1.31 a**
$LSD_{(0.05)}$	0.516	0.126	0.008	0.008	0.008	0.038
Significance level	0.01	0.01	0.01	0.01	0.01	0.01

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

Table 10. Interaction effect of sulphur and zinc on zinc concentration and uptake by grain , straw and post harvest soil of T-aman rice

Sulphur × Zinc	Zn concentration in grain (%)	Zn concentration in straw (%)	Zn uptake by grain (kg/ha)	Zn uptake by straw (kg/ha)	Total Zn uptake (kg/ha)	Zn in post harvest soil (ppm)
S_0Zn_0	19.90 h	11.05 g	0.060 d	0.050 c	0.110 f	0.53 e
S_0Zn_1	29.29 cd	16.15 d	0.102 bc	0.078b	0.180 d	1.10 b
S_0Zn_2	30.15 bc	17.35 b	0.106 bc	0.084 ab	0.190 bcd	1.28 a
$S_{12}Zn_0$	25.75 g	10.25 h	0.092 c	0.049 c	0.141 e	0.88 d
$S_{12}Zn_1$	29.33 cd	15.53 e	0.105 bc	0.076 b	0.181 d	1.17 b
$S_{12}Zn_2$	**32.00 a**	17.44 b	0.115 b	0.086 ab	0.201 bc	1.30 a
$S_{16}Zn_0$	28.00 ef	16.12 d	0.099 bc	0.078 b	0.177 d	0.96 c
$S_{16}Zn_1$	28.33 def	16.75 c	0.103 bc	0.083 ab	0.186 cd	1.14 b
$S_{16}Zn_2$	31.00 ab	17.56 b	0.116 b	0.090 ab	0.206 b	1.31 a
$S_{20}Zn_0$	27.65 f	15.06 f	0.098 bc	0.074 b	0.172 d	0.91 cd
$S_{20}Zn_1$	28.95 de	16.76 c	0.113 b	0.091 ab	0.204 bc	1.13 b
$S_{20}Zn_2$	**32.00 a**	**18.00 a**	**0.134 a**	**0.101 a**	**0.235 a**	**1.35 a**
$LSD_{(0.05)}$	1.033	0.251	0.017	0.017	0.017	0.076
Significance level	0.01	0.01	0.01	0.01	0.01	0.01
CV(%)	5.14	6.95	4.98	3.61	2.59	3.57

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

While the lowest (0.110 kg/ha) total uptake of Zn was recorded from the treatment combination of S_0Zn_0 i.e. control condition (Table 15).

4.3.6 Zn in post harvest soil

Statistically significant variation was observed for Zn in post harvest soil for the application of different level of sulphur in T-aman rice (Tab. 9). The highest (1.14 ppm) Zn in post harvest soil was recorded in S_{16} treatment (16 kg S/ha) which was statistically similar (1.13 ppm and 1.12 ppm) by S_{20} and S_{12} (20 kg and 12 kg S/ha respectively) and the lowest (0.97 ppm) Zn in post harvest soil was recorded in S_0 treatment (Table 9).

Zn in post harvest soil due to the application of different levels of zinc showed a statistically significant variation (Tab. 9). The highest (1.31 ppm) Zn in post harvest soil was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was closely followed (1.13 ppm) by Zn_1 (1 kg Zn/ha) and the lowest (0.82 ppm) Zn in post harvest soil was recorded in Zn_0 treatment. (Table 9). Ullah *et al.* (2001) found that soil Zn contents increased with $ZnS0_4$ application. Singh and Nongkynrih (2002) reported that only rice plants could utilize a fraction of total quantity of applied Zn. The availability of residual Zn for the next crop was also very low.

Interaction effect between sulphur and zinc in consideration of Zn in post harvest soil showed a statistically significant variation (Tab. 10). The highest (1.35 ppm) Zn in post harvest soil was recorded in the treatment combination of $S_{20}Zn_1$ (20 kg S/ha + 1 kg Zn/ha), while the lowest (0.53 ppm) Zn in post harvest soil was recorded in the treatment combination of S_0Zn_0 (Table 10).

.3 N concentrations in grain, straw, and post harvest soil

Concentration of N was estimated from the grain and straw sample, uptake of N by grain and straw and N in post harvest soil was measured.

4.3.1 N concentration in grain

Concentration of N in grain showed statistically non significant difference for the application of different levels of sulphur (Tab. 11). The highest (1.17%) concentration of N in grain was recorded in S_0 and S_{20} treatment consisting of 0 kg S/ha and 20 kg S/ha respectively and the lowest (1.15%) concentration of N in grain was recorded inS_{16} treatment (Table 11).

Concentration of N in grain due ot the application of different levels of zinc showed a statistically significant differences (Tab. 11). The highest (1.20%) concentration of N in grain was recorded in Zn_1 treatment (1 kg Zn/ha) and the lowest (1.14%) concentration of N in grain was recorded in Zn_2 treatment which was statistically identical (1.15%) with Zn_0 (Table 11).

Interaction effect between sulphur and zinc on N concentration in grain did not show statistically significant differences (Tab. 12). The highest (1.23%) concentration of N in grain was recorded in the treatment combination of S_0Zn_1 (0 kg S/ha + 1 kg Zn/ha), while the lowest (1.12%) concentration of N in grain was recorded in the treatment combination of S_0Zn_0, $S_{12}Zn_2$ and $S_{20}Zn_0$ (Table 12).

4.3.2 N concentration in straw

Concentration of N in straw showed statistically significant difference due to the application of different levels of sulphur in T-aman rice (Tab. 11). The highest (0.78%) concentration of N in straw was recorded in S_{20} treatment consisting of 20 kg S/ha which was statistically similar (0.77%) with S_{16} and the lowest (0.73%) concentration of N in straw was recorded in S_0 treatment (Table 11).

Statistically significant variation was recorded on concentration of N in straw due to the application of different levels of zinc (Tab. 11). The highest (0.78%) concentration of N in straw was recorded in Zn_1 treatment (1 kg Zn/ha) which was closely followed (0.75%) by Zn_2 treatment and the lowest (0.74%) concentration of N in straw was recorded in Zn_0 treatment (Table 11).

Interaction effect between sulphur and zinc on the N concentration in straw was not found statistically significant (Tab. 12). The highest (0.85%) concentration of N in straw was recorded from the treatment combination of S_0Zn_1 (0 kg S/ha + 1 kg Zn/ha), while the lowest (0.66%) concentration of N in straw was recorded in the treatment combination of S_0Zn_0 i.e. control condition (Table 12).

4.3.3 N uptake by grain

Due to the application of different level of sulphur in T-aman rice uptake of N by grain performed statistically significant difference (Tab.11). The highest (45.64 kg/ha) uptake of N by grain was recorded from S_{20} treatment consisting of 20 kg S/ha which was closely followed (41.94 kg/ha and 41.39 kg/ha) by S_{16} and S_{12} respectively (16 kg and 12 kg S/ha)and the lowest (39.07 kg/ha) uptake of N by grain was recorded in S_0 treatment (Table 11).

Statistically significant variation was observed due to the application of different levels of zinc on uptake of N by grain (Tab.11). The highest (43.86 kg/ha) uptake of N by grain was recorded in Zn_1 treatment (1 kg Zn/ha) which was statistically identical (43.40 kg/ha) with Zn_2 treatment (2 kg Zn/ha) and the lowest (38.78 kg/ha) uptake of N by grain was recorded in Zn_0 treatment (Table 11).

Statistically significant difference was recorded due to Interaction effect between sulphur and zinc on N uptake by grain (Tab. 12). The highest (49.98 kg/ha) uptake of N by grain was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (33.92 kg/ha) uptake of N by grain was recorded in the treatment combination of S_0Zn_0 i.e. without sulphur and zinc (Table 12).

4.3.4 N uptake by straw

Uptake of N by straw performed statistically significant difference due to the application of different levels of sulphur in T-aman rice (Tab. 11). The highest (41.71 kg/ha) uptake of N by straw was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (38.47 kg/ha) by S_{16} and the lowest (35.16 kg/ha) uptake of N by straw was recorded in S_0 treatment which was statistically identical (35.58 kg/ha) with S_{12} (Table 11).

Statistically significant difference was recorded on the uptake of N by straw due to the application of different levels of zinc (Tab. 11). The highest (39.07 kg/ha) uptake of N by straw was recorded from Zn_1 treatment (1 kg Zn/ha) which was statistically similar

(38.57 kg/ha) with Zn_2 treatment (2 kg Zn/ha) and the lowest (35.55 kg/ha) uptake of N by straw was recorded in Zn_0 treatment. (Table 11).

Interaction effect between sulphur and zinc on the N uptake by straw was found statistically significant (Tab. 12). The highest (44.39 kg/ha) uptake of N by straw was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (29.70 kg/ha) uptake of N by straw was recorded in the treatment combination of S_0Zn_0 i.e. control condition (Table 12).

4.3.5 Total N uptake

Total N uptake showed statistically significant variation due to the application of different levels of sulphur in T-aman rice (Tab. 11). The highest (87.35 kg/ha) total uptake of N was recorded in S_{20} treatment (20 kg S/ha) which was closely followed (80.41 kg/ha) by S_{16} and the lowest (74.24 kg/ha) total uptake of N was recorded in S_0 treatment which was statistically similar (76.97) with S_{12} (Table 11).

Total uptake of N due the application of different levels of zinc showed a statistically significant variation (Tab. 11). The highest (82.93 kg/ha) total uptake of N was recorded in Zn_1 treatment (1 kg Zn/ha) which was statistically similar (81.97 kg/ha) by Zn_2 as 2 kg Zn/ha and the lowest (74.33 kg/ha) total uptake of N was recorded inZn_0 treatment.(Table 11).

Interaction effect between sulphur and zinc on the total N uptake was found statistically significant (Tab. 12). The highest (94.37 kg/ha) total uptake of N was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (63.41

Table 11 Individual effect of sulphur and zinc on nitrogen concentration and uptake by grain and straw and post harvest soil of T-aman rice

Level of S and Zn	N concentration in grain (%)	N concentration in straw (%)	N uptake by grain (kg/ha)	N uptake by straw (kg/ha)	Total N uptake (kg/ha)	N in post harvest soil (%)
Sulphur						
S_0	**1.17**	0.74 bc	39.07 c	35.16 c	74.24 c	0.033 b
S_{12}	1.16	0.73 c	41.39 b	35.58 c	76.97 c	0.040 ab
S_{16}	1.15	0.77 ab	41.94 b	38.47 b	80.41 b	0.039 ab
S_{20}	**1.17**	**0.78 a**	**45.64 a**	**41.71 a**	**87.35 a**	**0.049 a**
$LSD_{(0.05)}$	--	0.031	1.532	2.112	3.048	0.009
Significance level	NS	0.01	0.01	0.01	0.01	0.01
Zinc						
Zn_0	1.14 b	0.74 b	38.78 b	35.55 b	74.33 b	0.036 b
Zn_1	1.20 a	0.78 a	43.86 a	39.07 a	82.93 a	0.047 a
Zn_2	1.15 b	0.75 b	43.40 a	38.57 a	81.97 a	0.039 ab
$LSD_{(0.05)}$	0.038	0.027	1.327	1.829	2.640	0.008
Significance level	0.01	0.01	0.01	0.01	0.01	0.01

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

Table 12. Interaction effect of sulphur and zinc on nitrogen concentration and uptake by grain , straw and post harvest soil of T-aman rice

Sulphur × Zinc	N concentration in grain (%)	N concentration in straw (%)	N uptake by grain (kg/ha)	N uptake by straw (kg/ha)	Total N uptake (kg/ha)	N in post harvest soil (ppm)
S_0Zn_0	1.12	0.66	33.71e	29.70 f	63.41 e	0.025 b
S_0Zn_1	**1.23**	**0.85**	42.92 c	40.80 abc	83.72 b	0.050 a
S_0Zn_2	1.15	0.72	40.59 cd	34.99 e	75.58 d	0.024 b
$S_{12}Zn_0$	1.16	0.74	40.71 cd	35.66 de	76.37 cd	0.036 ab
$S_{12}Zn_1$	1.21	0.73	43.19 c	35.59 de	78.78 bcd	0.046 a
$S_{12}Zn_2$	1.12	0.72	40.26 cd	35.49 de	75.75 d	0.039 ab
$S_{16}Zn_0$	1.16	0.79	40.94 cd	38.23 bcde	79.17 bcd	0.039 ab
$S_{16}Zn_1$	1.16	0.76	42.13 cd	37.77 cde	79.90 bcd	0.037 ab
$S_{16}Zn_2$	1.14	0.77	42.75 cd	39.42 bcd	82.17 bc	0.041 ab
$S_{20}Zn_0$	1.12	0.78	39.76 d	38.61 bcde	78.37 bcd	0.043 ab
$S_{20}Zn_1$	1.21	0.78	47.19 b	42.12 ab	89.31 a	**0.053 a**
$S_{20}Zn_2$	1.19	0.79	**49.98 a**	**44.39 a**	**94.37 a**	0.050 a
$LSD_{(0.05)}$	--	--	2.654	3.658	5.279	0.017
Significance level	NS	NS	0.01	0.01	0.01	0.01
CV(%)	3.78	4.09	3.73	5.73	3.91	2.87

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

Kg/ha) total uptake of N was recorded in the treatment combination of S_0Zn_0 i.e. control condition (Table 12).

4.3.6 N in post harvest soil

Statistically significant variations were observed on the N in post harvest soil due to the application of different levels of sulphur in T-aman rice (Tab. 11). The highest (0.049 %) N in post harvest soil was recorded in S_{20} treatment (20 kg S/ha) which was closely followed (0.040 % and 0.039 %) by S_{12} and S_{16} (12 kg and 16 kg S/ha), respectively and the lowest (0.033 %) N in post harvest soil was recorded in S_0 treatment (Table 11).

Statistically significant variation was recorded for N in post harvest soil due to the application of different levels of zinc (Tab.11). The highest (0.047 %) N in post harvest soil was recorded in Zn_1 treatment (1 kg Zn/ha) which was closely followed (0.039 %) by Zn_2 (2 kg Zn/ha)and the lowest (0.036 %) N in post harvest soil was recorded in Zn_0 treatment (Table 11).

Interaction effect between sulphur and zinc on the N conc. in post harvest soil was found statistically significant (Tab. 12). The highest (0.053 %) N in post harvest soil was recorded in the treatment combination of $S_{20}Zn_1$ (20 kg S/ha + 1 kg Zn/ha), while the lowest (0.024 %) N in post harvest soil was recorded in the treatment combination of S_0Zn_2 (Table 12).

4.4 P concentrations in grain, straw, and post harvest soil

Concentration of P was estimated from the grain and straw sample, uptake of P by grain and straw and P in post harvest soil was measured.

4.4.1 P concentration in grain

Due to the application of different levels of sulphur in T-aman rice. The concentration of P in grain showed statistically significant difference (Tab. 13). The highest (0.294%) concentration of P in grain was recorded in S_{20} treatment (20 kg S/ha) which was closely followed (0.287%) by S_{12} (12 kg S/ha) and the lowest (0.244%) concentration of P in grain was recorded in S_{16} treatment (Table 13).

Concentration of P in grain due to the application of different levels of zinc showed a statistically significant variation (Tab. 13). The highest (0.287%) concentration of P in grain was recorded in Zn_2 treatment (2 kg Zn/ha) which was closely followed (0.278%) by Zn_1 and the lowest (0.266%) concentration of P in grain was recorded from Zn_0 treatment (Table 13).

Interaction effect between sulphur and zinc on P concentration in grain showed a statistically significant variation (Tab. 14). The highest (0.297%) concentration of P in grain was recorded from the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (0.202%) concentration of P in grain was recorded in the treatment combination of S_0Zn_0, $S_{12}Zn_2$ and $S_{20}Zn_0$ (Table 14).

4.4.2 P concentration in straw

Concentration of P in straw showed statistically significant difference due to the application of different levels of sulphur in T-aman rice (Tab. 13). The highest (0.076%) concentration of P in straw was recorded in S_{20} treatment (20 kg S/ha) which was statistically similar (0.071%) with S_{16} as 16 kg and the lowest (0.061%) concentration of P in straw was recorded in S_0 treatment which was statistically identical (0.061%) with S_1 (Table 13).

Statistically significant variation was recorded for concentration of P in straw due to the application of different levels of zinc (Tab. 13). The highest (0.067%) concentration of P in straw was recorded in Zn_2 and Zn_1 treatments comprising of 2 kg and 1 kg Zn/ha respectively and the lowest (0.064%) concentration of P in straw was recorded from Zn_0 treatment (Table 13).

Interaction between sulphur and zinc in consideration of P concentration in straw showed a statistically significant difference (Tab. 14). The highest (0.079%) concentration of P in straw was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (0.053%) concentration of P in straw was recorded in the treatment combination of S_0Zn_0 (Table 14).

4.4.3 P uptake by grain

Due to the application of different levels of sulphur in T-aman rice uptake of P by grain showed statistically significant difference (Tab. 13). The highest (11.57 kg/ha) uptake of P by grain was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (10.41 kg/ha) by S_{16} (16 kg S/ha) and the lowest (8.21 kg/ha) uptake of P by grain was recorded in S_0 treatment which was closely followed (10.03 kg/ha) by S_{12} as 12 kg S/ha (Table 13).

A statistically significant difference was recorded for uptake of P by grain due to the application of different levels of zinc (Tab. 13). The highest (10.94 kg/ha) uptake of P by grain was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was closely followed (10.14 kg/ha) by Zn_1 treatment (1 kg Zn/ha) and the lowest (9.09 kg/ha) uptake of P by grain was recorded inZn_0 treatment (Table 13).

Interaction effect between sulphur and zinc in consideration of P uptake by grain was observed statistically significant (Tab. 14). The highest (12.97 kg/ha) uptake of P by grain was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (6.08 kg/ha) uptake of P by grain was recorded in the treatment combination of S_0Zn_0 i.e. without sulphur and zinc (Table 14).

4.4.4 P uptake by straw

Uptake of P by straw showed statistically significant variation due to the application of different levels of sulphur in T-aman rice (Tab. 13). The highest (4.06 kg/ha) uptake of P by straw was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (3.54 kg/ha) by S_{16} as 16 kg and the lowest (2.58 kg/ha) uptake of P by straw was recorded in S_0 treatment which was closely followed (2.94 kg/ha) by S_{12} as 12 kg S/ha (Table 13).

Statistically significant variation was recorded for uptake of P by straw due to the application of different levels of zinc (Tab. 13). The highest (3.46 kg/ha) uptake of P by straw was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was statistically similar (3.34 kg/ha) with Zn_1 treatment (1 kg Zn/ha) and the lowest (3.05 kg/ha) uptake of P by straw was recorded in Zn_0 treatment i.e. control condition (Table 13).

P uptake by straw due to interaction between sulphur and zinc performed a statistically significant difference (Tab. 14). The highest (4.43 kg/ha) uptake of P by straw was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (2.38 kg/ha) uptake of P by straw was recorded from the treatment combination of S_0Zn_0 i.e. control condition (Table 14).

4.4.5 Total P uptake

Total P uptake showed statistically significant difference due to the application of different levels of sulphur in T-aman rice (Tab. 13). The highest (15.64 kg/ha) total uptake of P was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (13.95 kg/ha) by S_{16} as 16 kg and the lowest (10.79 kg/ha) total uptake of P was recorded from S_0 treatment which was closely followed (12.97) by S_{12} (Table 13).

Statistically significant variation was recorded for total uptake of P due to the application of different levels of zinc (Tab. 13). The highest (14.40 kg/ha) total uptake of Zn was recorded from Zn_2 treatment (2 kg Zn/ha) which was closely followed (13.47 kg/ha) by Zn_1 (1 kg Zn/ha)and the lowest (12.14 kg/ha) total uptake of P was recorded in Zn_0 treatment i.e. control condition (Table 13).

Interaction effect between sulphur and zinc in consideration of total P uptake was found statistically significant (Tab. 14). The highest (17.40 kg/ha) total uptake of P was recorded from the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (8.46 kg/ha) total uptake of P was recorded in the treatment combination of S_0Zn_0 i.e. control condition (Table 14).

Table 13. Individual effect of sulphur and zinc on phosphorus concentration and uptake by grain , straw and post harvest soil of T-aman rice

Levels of S and Zn	P concentration in grain (%)	P concentration in straw (%)	P uptake by grain (kg/ha)	P uptake by straw (kg/ha)	Total P uptake (kg/ha)	P in post harvest soil (ppm)
Sulphur						
S_0	0.244 c	0.055 b	8.21 d	2.58 d	10.79 d	18.46 d
S_{12}	0.283 b	0.061 b	10.03 c	2.94 c	12.97 c	19.58 c
S_{16}	0.287 ab	0.071 a	10.41 b	3.54 b	13.95 b	21.02 b
S_{20}	**0.294 a**	**0.076 a**	**11.57 a**	**4.06 a**	**15.64 a**	**23.16 a**
$LSD_{(0.05)}$	0.009	0.009	0.323	0.191	0.486	0.169
Significance level	0.01	0.01	0.01	0.01	0.01	0.01
Zinc						
Zn_0	0.266 c	0.064 b	9.09c	3.05 b	12.14 c	20.57 b
Zn_1	0.278 b	0.067 a	10.14 b	3.34 a	13.47 b	20.74 a
Zn_2	0.287 a	0.067 a	10.94 a	3.46 a	14.40 a	20.37 c
$LSD_{(0.05)}$	0.08	0.08	0.280	0.165	0.421	0.147
Significance level	0.01	0.01	0.01	0.01	0.01	0.01

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

Table 14. Interaction effect of sulphur and zinc on phosphorus concentration and uptake by grain , straw and post harvest soil of T-aman rice

Sulphur × Zinc	P concentration in grain (%)	P concentration in straw (%)	P uptake by grain (kg/ha)	P uptake by straw (kg/ha)	Total P uptake (kg/ha)	P in post harvest soil (ppm)
S_0Zn_0	0.202 c	0.053 d	6.08 f	2.38 f	8.46 g	19.34 g
S_0Zn_1	0.250 b	0.054 cd	8.72 e	2.59 ef	11.31 f	17.55 j
S_0Zn_2	0.279 a	0.057 cd	9.84 d	2.77 e	12.61 e	18.50 i
$S_{12}Zn_0$	0.284 a	0.058 bcd	9.86 d	2.79 e	12.65 e	19.89 f
$S_{12}Zn_1$	0.283 a	0.065 abcd	10.10 d	3.14 cd	13.24 de	19.99 f
$S_{12}Zn_2$	0.282 a	0.059 bcd	10.12 d	2.90 de	13.02 de	18.87 h
$S_{16}Zn_0$	0.286 a	0.071 abcd	10.09 d	3.43 bc	13.52 de	20.54 e
$S_{16}Zn_1$	0.285 a	0.070 abcd	10.31 cd	3.47 bc	13.78 cd	20.97 d
$S_{16}Zn_2$	0.290 a	0.072 abcd	10.83 c	3.73 b	14.56 c	21.56 c
$S_{20}Zn_0$	0.291 a	0.073 abc	10.33 cd	3.61 b	13.94 cd	22.51 b
$S_{20}Zn_1$	0.293 a	0.077 ab	11.42 b	4.15 a	15.57 b	**24.44 a**
$S_{20}Zn_2$	**0.297 a**	**0.079 a**	**12.97 a**	**4.43 a**	**17.40 a**	22.54 b
$LSD_{(0.05)}$	0.017	0.017	0.559	0.330	0.842	0.293
Significance level	0.01	0.01	0.01	0.01	0.01	0.01
CV(%)	2.74	2.78	3.28	5.97	6.72	7.84

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

4.4.6 P in post harvest soil

Statistically significant variation was observed for P in post harvest soil due to the application of different levels of sulphur in T-aman rice (Tab. 13). The highest (23.16 ppm) P in post harvest soil was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (21.02 ppm) by S_{16} (16 kg S/ha) and the lowest (18.46 ppm) P in post harvest soil was recorded in S_0 treatment which was closely followed (19.58 ppm) by S_{12} (Table 13)

Due to the application of different levels of zinc a statistically significant variation was recorded for P in post harvest soil (Tab. 13). The highest (20.74 ppm) P in post harvest soil was recorded in Zn_1 treatment comprising of 1 kg Zn/ha which was closely followed (20.57 ppm) by Zn_0 and the lowest (20.37 ppm) P in post harvest soil was recorded in Zn_2 treatment (2 kg Zn/ha)(Table 13).

Interaction effect between sulphur and zinc in consideration of P in post harvest soil was found statistically significant differences (Tab. 14). The highest (24.44 ppm) P in post harvest soil was recorded in the treatment combination of $S_{20}Zn_1$ (20 kg S/ha + 1 kg Zn/ha), while the lowest (18.50 ppm) P in post harvest soil was recorded in the treatment combination of S_0Zn_2 (Table 14).

4.5 K contents in grain, straw, and post harvest soil

Concentration of K was estimated from the grain and straw sample, uptake of K by grain and straw and K in post harvest soil was measured.

4.5.1 K concentration in grain

Concentration of K in grain showed statistically significant difference due to the application of different levels of sulphur in T-aman rice (Tab. 15). The highest (0.73%) concentration of K in grain was recorded S_{20} treatment consisting of 20 kg S/ha which was closely followed (0.71%) by S_{16} (16 kg S/ha) and the lowest (0.62%) concentration of K in grain was recorded in S_0 treatment which was closely followed (0.66%) by S_{12} .

A statistically significant difference was recorded for concentration of K in grain due to the application of different levels of zinc (Tab. 15). The highest (0.69%) concentration of K in grain was recorded in Zn_1 and Zn_2 treatment comprising of 1 and 2 kg Zn/ha, respectively. On the other hand, the lowest (0.67%) concentration of K in grain was recorded in Zn_0 treatment (Table 15).

Interaction effect between sulphur and zinc on the K concentration in grain was found statistically significant (Tab. 16). The highest (0.76%) concentration of K in grain was recorded in the treatment combination of $S_{20}Zn_1$ (20 kg S/ha + 1 kg Zn/ha), while the lowest (0.61%) concentration of K in grain was recorded in the treatment combination of S_0Zn_0, and S_0Zn_1 (Table 16).

4.5.2 K concentration in straw

Concentration of K in straw showed statistically significant difference due to the application of different levels of sulphur in T-aman rice (Tab. 15). The highest (2.32%) concentration of K in straw was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (2.20%) by S_{16} and the lowest (1.79%) concentration of K in straw was recorded in S_0 treatment which was closely followed (2.17%) by S_{12} (12 kg S/ha) (Table 15).

Concentration of K in straw due to the application of different levels of zinc showed a statistically significant variation (Tab. 15). The highest (2.17%) concentration of K in straw was recorded in Zn_1 treatment (1 kg Zn/ha) which was closely followed (2.13%) by Zn_2 (2 kg Zn/ha)and the lowest (2.06%) concentration of K in straw was recorded in Zn_0 treatment (Table 15).

Interaction effect between sulphur and zinc in consideration of K concentration in straw performed statistically significant differences (Tab. 16). The highest (2.40%) concentration of K in straw was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (1.57%) concentration of K in straw was recorded from the treatment combination of S_0Zn_0 i.e. control condition (Table 16). Khan *et al.* (1996) observed that combined application of gypsum and Zn was effective in increasing total concentrations of K in plant tissue.

4.5.3 K uptake by grain

Uptake of K by grain showed statistically significant difference due to the application of different levels of sulphur in T-aman rice (Tab. 15). The highest (28.48 kg/ha) uptake of K by grain was recorded in S_{20} treatment (20 kg S/ha) which was closely followed (25.93 kg/ha) by S_{16} (16 kg S/ha) and the lowest (20.62 kg/ha) uptake of K by grain was recorded in S_0 treatment which was closely followed (23.45 kg/ha) by S_{12} (12 kg S/ha) (Table 15).

Statistically significant variation was recorded for uptake of K by grain due to the application of different levels of zinc (Tab. 15). The highest (25.98 kg/ha) uptake of K by grain was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was statistically similar (25.13 kg/ha) with Zn_1 treatment (1 kg Zn/ha) and the lowest (22.76 kg/ha) uptake of K by grain was recorded in Zn_0 treatment (Table 15).

Interaction effect between sulphur and zinc in consideration of K uptake by grain was observed statistically significant (Tab. 16). The highest (30.24 kg/ha) uptake of K by grain was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha) and the lowest (18.36 kg/ha) uptake of K by grain was recorded in the treatment combination of S_0Zn_0 i.e. without sulphur and zinc (Table 16).

4.5.4 K uptake by straw

For the application of different levels of sulphur in T-aman rice the uptake of K by straw showed statistically significant difference (Tab. 15). The highest (123.41 kg/ha) uptake of K by straw was recorded in S_{20} treatment (20 kg S/ha) which was closely followed (109.51 kg/ha) by S_{16} and the lowest (84.88 kg/ha) uptake of K by straw was recorded in S_0 treatment which was closely followed (105.64 kg/ha) by S_{12} (12 kg S/ha) (Table 16).

Statistically significant variation was recorded for uptake of K by straw due to the application of different levels of zinc (Tab.15). The highest (109.62 kg/ha) uptake of K by straw was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was statistically similar (109.06 kg/ha) with Zn_1 treatment (1 kg Zn/ha) and the lowest (98.90 kg/ha) uptake of K by straw was recorded in Zn_0 treatment i.e. control condition (Table 15).

A statistically significant difference was recorded for the interaction effect between sulphur and zinc in consideration of K uptake by straw (Tab. 16). The highest (134.88 kg/ha) uptake of K by straw was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (70.65 kg/ha) uptake of K by straw was recorded in the treatment combination of S_0Zn_0 i.e. control treatment (Table 16).

4.5.5 Total K uptake

Total K uptake showed statistically significant difference for the application of different levels of sulphur in T-aman rice (Tab. 15). The highest (151.89 kg/ha) total uptake of K was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (135.44 kg/ha) by S_{16} and the lowest (105.50 kg/ha) total uptake of K was recorded in S_0 treatment which was closely followed (129.09) by S_{12} (Table 15).

Statistically significant variation was recorded for total uptake of K due to the application of different levels of zinc (Tab. 15). The highest (135.60 kg/ha) total uptake of K was recorded in Zn_2 treatment comprising of 2 kg Zn/ha which was statistically identical (134.19 kg/ha) with Zn_1 (1 kg Zn/ha) and the lowest (121.65 kg/ha) total uptake of K was recorded in Zn_0 treatment . (Table 15).

Interaction effect between sulphur and zinc in consideration of total K uptake was found statistically significant (Tab. 16). The highest (165.12 kg/ha) total uptake of K was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (89.01 kg/ha) total uptake of K was recorded in the treatment combination of S_0Zn_0 i.e. control treatment (Table 16).

Table 15. Individual effect of sulphur and zinc on potassium concentration and uptake by grain , straw and post harvest soil of T-aman rice

Sulphur × Zinc	K in grain (%)	K in straw (%)	K uptake by grain (kg/ha)	K uptake by straw (kg/ha)	Total K uptake (kg/ha)	K in post harvest soil (meq/100 g soil)
Sulphur						
S_0	0.62 d	1.79 d	20.62 d	84.88 d	105.50 d	0.127 c
S_{12}	0.66 c	2.17 c	23.45 c	105.64 c	129.09 c	0.138 b
S_{16}	0.71 b	2.20 b	25.93 b	109.51 b	135.44 b	0.145 ab
S_{20}	**0.73 a**	**2.32 a**	**28.48 a**	**123.41 a**	**151.89 a**	**0.150 a**
$LSD_{(0.05)}$	0.009	0.031	1.271	3.799	3.954	0.009
Significance level	0.01	0.01	0.01	0.01	0.01	0.01
Zinc						
Zn_0	0.67 b	2.06 c	22.76 b	98.90 b	121.65 b	0.121 b
Zn_1	**0.69 a**	**2.17 a**	25.13 a	109.06 a	134.19 a	0.149 a
Zn_2	**0.69 a**	2.13 b	**25.98 a**	**109.62 a**	**135.60 a**	**0.150 a**
$LSD_{(0.05)}$	0.008	0.027	1.100	3.290	3.425	0.008
Significance level	0.01	0.01	0.01	0.01	0.01	0.01

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

Table 16. Interaction effect of sulphur and zinc on potassium concentration and uptake by grain , straw and post harvest soil of T-aman rice

Sulphur × Zinc	K in grain (%)	K in straw (%)	K uptake by grain (kg/ha)	K uptake by straw (kg/ha)	Total K uptake (kg/ha)	K in post harvest soil (c mol/kg soil)
S_0Zn_0	0.61 h	1.57 h	18.36 g	70.65 g	89.01 h	0.101 e
S_0Zn_1	0.61 h	1.96 f	21.28 f	94.08 f	115.36 g	0.139 abc
S_0Zn_2	0.63 g	1.85 g	22.23 ef	89.91 f	112.14 g	0.142 abc
$S_{12}Zn_0$	0.65 f	2.22 c	22.75 ef	107.03 cde	129.78 ef	0.115 de
$S_{12}Zn_1$	0.67 e	2.23 c	23.91 de	108.82 cd	132.73 de	0.151 ab
$S_{12}Zn_2$	0.66 ef	2.05 e	23.69 de	101.06 e	124.75 f	0.148 abc
$S_{16}Zn_0$	0.69 d	2.15 d	24.35 de	104.06 de	128.41 ef	0.130 cd
$S_{16}Zn_1$	0.71 c	2.25 bc	25.70 cd	111.82 c	137.52 cd	0.152 ab
$S_{16}Zn_2$	0.74 b	2.20 cd	27.75 bc	112.64 c	140.39 c	0.153 ab
$S_{20}Zn_0$	0.72 c	2.30 b	25.56 cd	113.85 c	139.41 cd	0.137 bc
$S_{20}Zn_1$	**0.76 a**	2.25 bc	29.64 ab	121.50 b	151.14 b	0.155 ab
$S_{20}Zn_2$	0.72 c	**2.40 a**	**30.24 a**	**134.88 a**	**165.12 a**	**0.158 a**
$LSD_{(0.05)}$	0.017	0.053	2.201	6.580	6.849	0.017
Significance level	0.05	0.01	0.01	0.01	0.01	0.01
CV(%)	6.64	8.14	5.28	3.67	3.10	2.57

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

4.5.6 K in post harvest soil

Statistically significant variation was recorded for K in post harvest soil due to the application of different levels of sulphur in T-aman rice (Tab. 15). The highest (0.150 c mol/kgsoil) K in post harvest soil was recorded in S_{20} treatment (20 kg S/ha) which was statistically similar (0.145 c mol/ kg soil) with S_{16} as (16 kg
S/ha) and the lowest (0.127 C mol/ kg soil) K in post harvest soil was recorded in S_0 treatment which was closely followed (0.138 C mol/kg soil) by S_{12} (Table 15).

Statistically significant variation was recorded for K in post harvest soil due to the application of different levels of zinc (Tab. 15). The highest (0.150 C mol/ kg soil) K in post harvest soil was recorded in Zn_2 treatment (2 kg Zn/ha) which was statistically identical (0.149 C mol/kg soil) with Zn_1 (1 kg Zn/ha) and the lowest (0.121 C mol/kg soil) K in post harvest soil was recorded in Zn_0 treatment.

Interaction effect between sulphur and zinc in consideration of K in post harvest soil showed statistically significant differences (Tab. 16). The highest (0.158C mol/kg soil) K in post harvest soil was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the lowest (0.101C mol/ kg soil) K in post harvest soil was recorded in the treatment combination of S_0Zn_0 (Table 16).

4.4 Soil pH

Soil pH differed significantly for the application of different levels of sulphur in T-aman rice (Fig.7). The maximum soil pH (6.38) was recorded in S_{20} treatment consisting of 20 kg S/ha which was closely followed (6.11) by S_{12} and S_{16} treatments, while the minimum soil pH (6.00) was recorded in S_0 treatment. (Figure7).

Statistically non significant difference was recorded for soil pH due to the application of different levels of zinc (Fig. 8). The maximum soil pH (6.25) was recorded in Zn_0 treatment and the minimum soil pH (6.09) was recorded in Zn_2 treatment (2 kg Zn/ha) (Figure 8). Dunn *et al*. (2002) stated that soil pH had a significant effect on the extractable Zn following two years of applying $ZnSO_4$ fertilizer but soil pH did not significantly affect plant Zn concentrations.

Interaction effect between Sulphur and zinc on soil pH and found statistically significant (Fig. 9). The maximum soil pH (6.35) was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha), while the minimum soil pH (5.90) was recorded from the treatment combination of S_0Zn_2 and S_1Zn_2 (Fig. 9).

4.5 Organic matter in soil

Due to the application of different levels of Sulphur in T-aman rice organic matter content in soil differed significantly (Fig. 10). The maximum organic matter in soil (1.34%) was recorded in S_{16} treatment (16 kg S/ha) which was statistically identical (1.30%) with S_{20} treatment, while the minimum organic matter content in soil (1.21%) was recorded in S_1 treatment which was statistically similar (1.23%) with S_{12} treatment (Fig. 10). Sharma and Gangwar (1997) observed that total S, organic S, heat soluble S, NaH_2P0_4 extractable S and $CaC1_2$ extractable S were correlated significantly with organic carbon of Soil.

A Statistically significant variation was observed on organic matter content in soil due to the application of different levels of zinc (Fig. 11). The maximum organic matter content in soil (1.31%) was recorded in Zn_2 treatment (2 kg Zn/ha) which was statistically identical (1.29%) with Zn_1 treatment (1 kg Zn/ha) and the minimum organic matter content in soil (1.22%) was recorded in Zn_0 treatment (Fig. 11). Mythili *et al.* (2003) stated that micronutrient cycling in soils is closely associated with organic matter turnover because it is intricately related with trace elements.

Organic matter content in soil showed a statistically significant difference due to the interaction effect of sulphur and zinc (Fig. 12). The maximum organic matter content in soil (1.43%) was recorded in the treatment combination of $S_{20}Zn_2$ (20 kg S/ha + 2 kg Zn/ha) and the minimum organic matter content in soil (1.18) was recorded in the treatment combination of S_0Zn_2 (Fig.12).

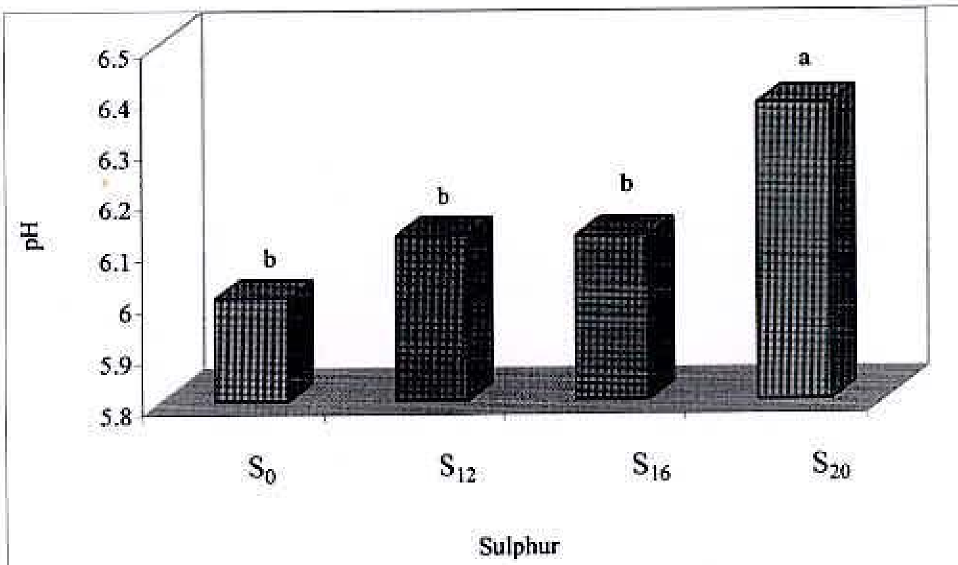

Figure 7. Effect of sulphur on soil pH in the postharvest soil of T-aman rice

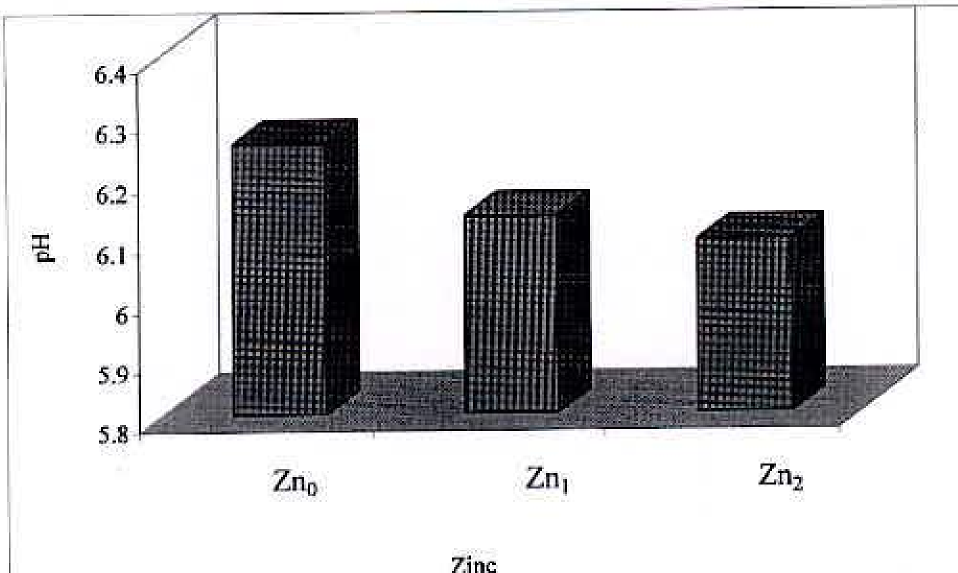

Figure 8. Effect of zinc on soil pH in the post harvest soil of T-aman rice

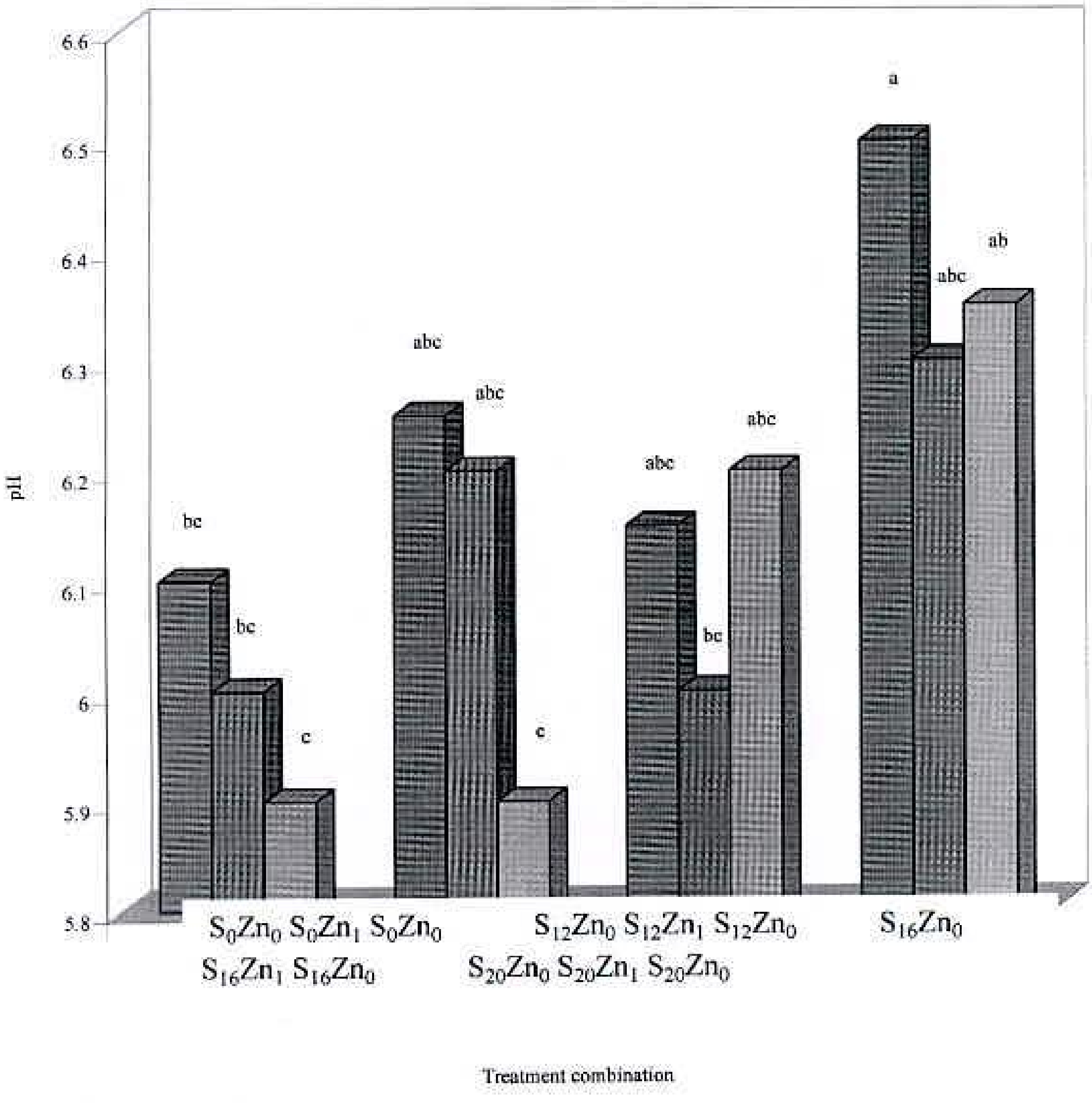

Figure 9. Interaction effect of sulphur and zinc on soil pH on the post harvest soil of T-aman rice

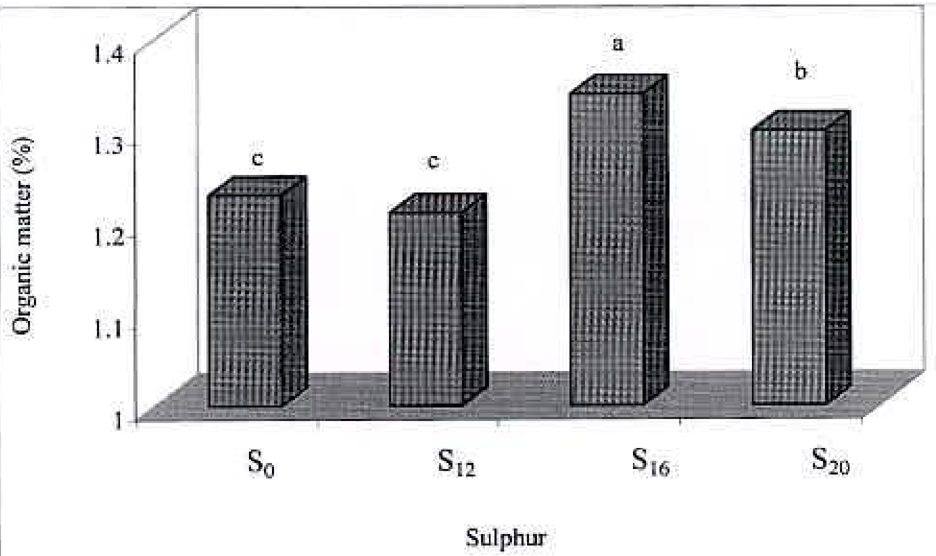

Figure 10. Effect of sulphur on organic matter content in the postharvest soil of T-aman rice

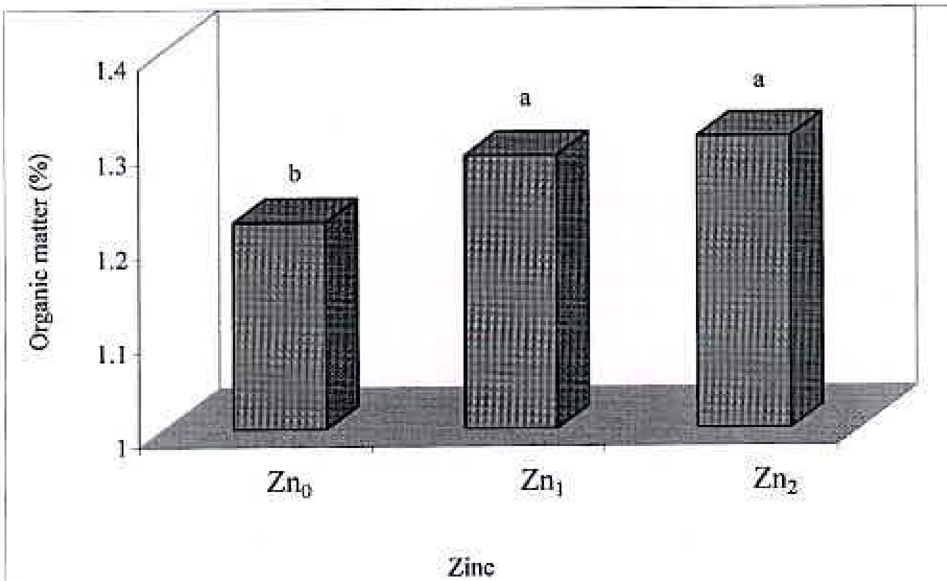

Figure 11. Effect of zinc on organic matter content in the postharvest soil of T-aman rice

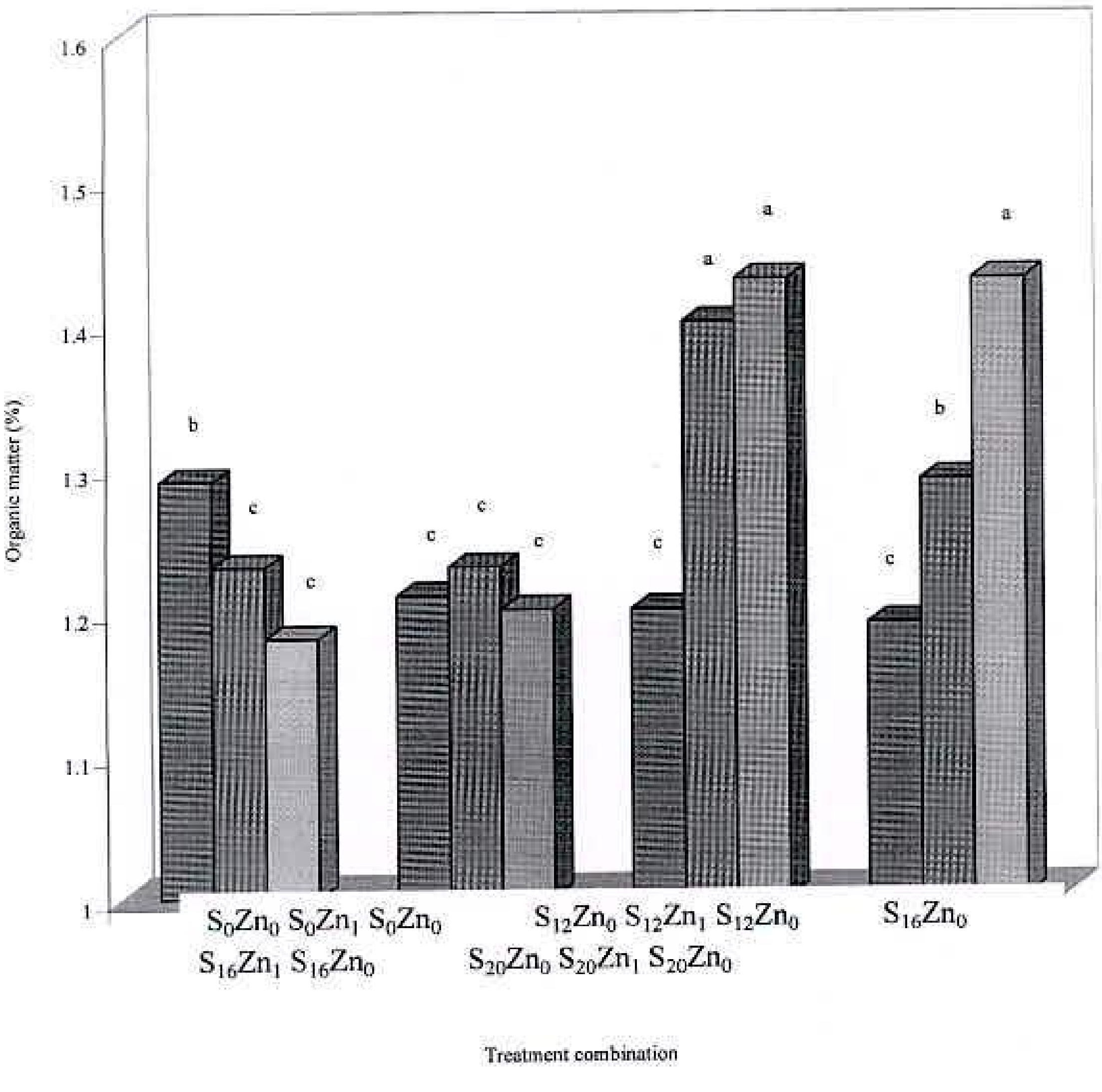

Figure 12. Interaction effect of sulphur and zinc on soil organic matter content in the postharvest soilof T-aman rice

4.6 Economic analysis

The analysis was done in order to find out the most profitable treatment based on cost and benefit of various treatments. Net benefit was calculated by subtracting the total input cost from the gross field income. Gross field income was calculated as the total market value of grain and straw of rice. The input cost was calculated as the total market value of fertilizers, other material, and non-material cost. The results if economic analysis of rice (BRRI dhan 31) showed that the highest net benefit of Tk. 42170/ha was obtained in T_{11} followed by Tk. 37280, Tk.34920, Tk.33161, Tk. 32790, Tk. 32690, Tk. 32621, Tk. 31791, Tk. 31751, Tk.31450, Tk. 24233/ha in T_{10},T_8,T_5,T_7,T_2,T_4,T_6,T_3,T_9,T_1 and T_0 treatments respectively.

Table 17 Economics for fertilizer use in crop production under rice (BRRI Dhan 31) during Aman season (2007)

Treatments	Total output Kg/ha		Gross field income Tk/ha			Total input costTk/ha	Net benefit Tk/ha
	grain	Straw	Grain	Straw	Total		
T_0(0Z0)	3010	4500	48160	4500	52660	28430	24223
T_1(S01)	3490	4800	55840	4800	60640	28500	32140
T_2(S0Z2)	3530	4860	56480	4860	61340	28650	32690
T3(S12Z0)	3510	4820	56160	4820	60980	29229	31751
T4(S12Z1)	3570	4880	57120	4880	62000	29379	32621
T_5S12Z2)	3616	4930	57760	4930	62690	29529	33161
T6S16Z0)	3530	4840	56480	4840	61320	29601	31791
T_7(S16Z1)	3620	4970	57920	4970	62890	30100	32790
T_8(S16Z2)	3750	5120	60000	5120	65120	30200	34920
T_9(S20Z0)	3550	4950	56800	4950	61750	30300	31450
T_{10}(S20Z1)	3900	5380	62400	5380	67780	30500	37280
T_{11}(S20Z2)	4200	5620	67200	5620	72820	30650	42170

summary and conclusion

SUMMARY AND CONCLUSION

The present experiment was conducted to determine the effect of different levels of Sulphur and zinc on the yield contributing characters and yield of T-aman rice as well as the nutrient concentration and their uptake by grain and straw and also the amount of remaining nutrients in post harvest soil. There were twelve treatments combination with various combinations of S (0, 12, 16 and 20 kg/ha and Zn (0, 1 and 2 kg/ha) doses including control. Among the parameters, the grain yield was the most important important parameter in this study. The highest grain yield was recorded in S20 and Zn2 treatment. The treatment combination of $S_{20}Zn_2$ gave the highest grain yield (4.20).

The highest straw yield was recorded in S_{20} and Zn_2 treatment. The treatment combination of $S_{20}Zn_2$ gave the highest straw yield (5.62 ton/ha).

The maximum plant height was recorded in S_{20} and Zn_2 treatment. The treatment combination of $S_{16}Zn_2$ gave the maximum plant height (129.31 cm).

The maximum number of effective effective tillers/hill was recorded in S_{20} and Zn_2 treatment. The treatment combination of $S_{20}Zn_2$ gave the maximum number of effective tillers/hill (12.40).

The maximum number of total tillers/hill was recorded in S_{20} and Zn2 treatment. The treatment combination of $S_{20}Zn_2$ gave the highest number of total tillers/hill (13.52).

The highest panicle length was recorded in S_{20} and Zn_2 treatment. The treatment combination of $S_{20}Zn_2$ gave the highest panicle length (29.49 cm).

The maximum number of filled grains/panicle was recorded in S_{20} and Zn_2 treatment .The treatment combination of $S_{20}Zn_2$ gave the maximum number of filled grains/panicle (72.05).

The highest number of total grains/panicle was recorded in S_{16} and Zn_2 treatment. The treatment combination of$S_{20}Zn_2$ gave the highest number of total grains/panicle (82.55).

The highest total S uptake was recorded in S_{20} and Zn_2 treatment. The treatment combination of $S_{20}Zn_2$ gave the highest total S uptake (13.05 Kg/ha).

The highest S content in post harvest soil was recorded in S20 and Zn2 treatment. The treatment combination of $S_{20}zn_2$ gave the highest S content in post harvest soil (21.05 ppm).

The highest total Zn uptake was recorded in S20 and Zn2 treatment .The treatment combination of $S_{20}Zn_2$ gave the highest total Zn uptake(0.235 kg/ha).

The highest Zn content in post harvest soil was recorded in S_{16} and Zn_2 treatment. The treatment combination of $S_{20}Zn_2$ gave the highest Zn content in post harvest soil (1.35 ppm).

The highest total P uptake was recorded in S_{20} and Zn_2 treatment. The treatment combination of $S_{20}Zn_2$ gave the highest total P uptake (17.40 kg/ha).

The highest P in post harvest soil was recorded in S20 and Zn1 treatment. The treatment combination of $S_{20}Zn_2$ gave the highest P content in post harvest soil (17.40 kg/ha).

The highest total K uptake was recorded in S20 and Zn_2 treatment. The treatment combination of $S_{20}Z_{n2}$ gave the highest total K uptake (165.12 kg/ha).

The highest K content in post harvest soil was recorded in S20 and Zn2 treatment. The treatment combination of $S_{20}Zn_2$ gave the highest K content in post harvest soil (0.158 C mol/kg).

The maximum soil pH in post harvest soil was recorded in S20 and Zn0 treatment. The treatment combination of $S_{20}Zn_2$ gave the maximum soil pH (6.35).

The maximum organic matter content in post harvest soil was recorded in S_{16} and Zn_2 treatment. The treatment combination of $S_{20}Zn_2$ gave the highest organic matter content in post harvest soil (1.43%).

Considering the situation of the present experiment, further studies in the following areas may be suggested:

1. Such study is needed in different agro-ecological zones (AEZ) of Bangladesh for regional adaptability and other performances;
2. Another level of Sulphur and zinc and time of application may be included in the further study;
3. Another fertilizer or combined fertilizer may also included in the program for future study.

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Appendix 1. Monthly record of air temperature (°C), relative humidity (%), rainfall (mm), and sunshine hours during the period from July to October 2007.

Months	Air temperature (°c)			Relative humidity (%)	Rain fall (mm)	Sunshine (Hrs.)
	Maximum	Minimum	Average			
July	34.72	27.28	31.26	78.90	180	230
August	33.1	27.8	*30.45*	82.34	170	227.90
September	30.2	20.57	*25.38*	83.23	110	171.5
October	27	19	23	*85.25*	40	145

Source: Department of climatological observations (monthly). Dhaka weather office, Agargaon.