EFFECTS OF SULPHUR AND BORON ON GROWTH, YIELD AND NUTRIENT CONTENT OF T.AMAN RICE (*Oryza sativa*)

BY

TAJNUVA AFROZ

Reg. No.: 05-01614

A Thesis
Submitted to the Department of Agricultural Chemistry
Sher-e-Bangla Agricultural University, Dhaka
In partial fulfillment of the requirements
for the degree
of

MASTER OF SCIENCE (MS)
IN

AGRICULTURAL CHEMISTRY
SEMESTER: JANUARY-JUNE 2011

APPROVED BY:

Md. Shahjahan Miah
Professor
Department of Agricultural Chemistry
SAU, Dhaka
Supervisor

Dr. Sheikh Shawkat Zamil
Assistant Professor
Department of Agricultural Chemistry
SAU, Dhaka
Co-Supervisor

Prof. Dr. Rokeya Begum
Chairman
Examination Committee

DEPARTMENT OF AGRICULTURAL CHEMISTRY
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207

Memo No: SAU/AGCH/

CERTIFICATE

This is to certify that the thesis entitled **"Effects of sulphur and boron on growth, yield and nutrient content of T.aman rice"** submitted to the Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE in AGRICULTURAL CHEMISTRY**, embodies the result of a piece of bona fide research work carried out by **TAJNUVA AFROZ**, Registration Number: **05-1614** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated: June, 2011
Dhaka, Bangladesh

Prof. Md. Shahjahan Miah
Department of Agricultural Chemistry
Sher-e-Bangla Agricultural University
Dhaka-1207
Supervisor

DEDICATED

TO

MY BELOVED PARENTS

ACKNOWLEDGEMENTS

All praises are devoted to Almighty Allah, the omnipresent and omnipotent who is the supreme authority of this universe, and who has kindly enabled me to complete this research work and to submit the thesis for the degree of Master of Science (MS) in Agricultural Chemistry.

It is a privilege to express sincere gratitude and appreciation to my respected supervisor Md. Shahjahan Miah, Professor, Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka for providing invaluable advice, Scholastic guidance, constant encouragement and motivation on my academic and research work during the whole period of study and for his constructive suggestions in preparing the manuscript of the thesis.

I gratefully express my deepest sense of respect to my co-supervisor Dr. Sheikh Shawkat Zamil, Assistant Professor, Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka for his valuable suggestions, relevant comments, keen interest and co-operation.

I express my sincere respect to Prof. Dr. Rokeya Begum and Prof. Dr. Md. Abdur Razzaque, Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka for their encouragement, visiting the experimental site, valuable advice to complete this research and preparing the thesis.

I would like to extend my grateful acknowledgement and sincere respect to Prof. Md. Azizur Rahman Mazumder, Prof. Dr. Noorjahan Begum and Assistant Prof. Md. Tazul Islam Chowdhury, Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University, Dhaka for their valuable suggestions and co-operation during the work.

I convey my honest thanks to all the staff members and laboratory assistants of the Department of Agricultural Chemistry and farm of Sher-e-Bangla Agricultural University, Dhaka for their help in conducting the experiment.

Diction is not enough to express my profound gratitude and deepest appreciation to my beloved father " Md. Belayat Hossain," mother " Afroza Ahmed" for their unlimited prayer, support, sacrifice and inspiration to educate me up to this level.

The Author
June, 2011
SAU, Dhaka

ABSTRACT

The experiment was conducted at Sher-e-Bangla Agricultural University (SAU) farm, Sher-e-Bangla Nagar, Dhaka, Bangladesh during the period of July 2011 to November 2011 to study the effect of sulphur and boron on growth, yield and nutrient content of T. aman rice. BRRI dhan 30 was used as the test crop in this experiment. This experiment was laid out in randomized complete block design (RCBD). There were sixteenth treatment combinations comprising of four levels of sulphur (0, 8, 12, 16 kg ha^{-1}) designated as S_0, S_1, S_2 and S_3 and four levels of boron (0, 1, 1.5 and 2 kg ha^{-1}) designated as B_0, B_1, B_2 and B_3 respectively. In case of individual effect of sulphur the maximum plant height (116.96 cm), number of effective tillers $hill^{-1}$ (9.09), panicle length (25.64 cm), number of filled grains $panicle^{-1}$ (102.42) and grain yield (4.89 t ha^{-1}) was recorded in S_2 treatment (12 kg S ha^{-1}) . The straw yields were almost similar in different levels of sulphur except S_0 treatment. Application of 1 kg B ha^{-1} produced the highest number of effective tillers $hill^{-1}$ (8.98), panicle length (25.73 cm), filled grains $panicle^{-1}$ (97.60), grain yield (4.99 t ha^{-1}) and straw yield (7.08 t ha^{-1}). There was no significant effect of boron on number of unfilled grains $panicle^{-1}$, and 1000-grain weight of BRRI dhan 30. The treatment combination of S_2B_1 (12 kg S ha^{-1} + 1 kg B ha^{-1}) performed better than other treatments in present trial considering number of effective tillers $hill^{-1}$, number of panicle length, filled grains $panicle^{-1}$, grain yield and straw yield of T.aman rice (BRRI dhan 30). The nutrient concentrations of N, P, K, S and B in grain and straw increased with increasing levels of S and B. From the view point of grain yield and nutrient content, the treatment combination of S_2B_1 (12 kg S ha^{-1} + 1 kg B ha^{-1}) was considered to be the suitable dose of fertilizer for T. aman rice.

ABBREVIATIONS AND ACRONYMS

Full word	**Abbreviation**
And others (at elli)	*et al.,*
Centimeter	cm
Concentrate	Conc.
Cultivar	cv.
Cowdung	CD
Degree Celsius	°C
Degree of freedom	df
Emulsifiable Concentrate	EC
Gram	g
Granular	G
Hectare	ha
Hydrogen ion conc.	pH
Kilogram	kg
Least significant difference	LSD
Liter	L
Meter	m
Microgram	µg
Milliequivalent	meq
Milligram	mg
Milliliter	mL
Millimeter	mm
Nanometer	nm
Parts per million	ppm
Pound	lb
Poultry Manure	PM
Square centimeter	cm^2
Square meter	m^2
Ton	t

LIST OF CONTENTS

CONTENTS (Contd.)

CONTENTS (Contd.)

CONTENTS (Contd.)

CONTENTS (Contd.)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER I
INTRODUCTION

CHAPTER I
INTRODUCTION

Bangladesh is an agro-based country where about 19.95% of her total gross domestic product (GDP) comes from agriculture. Agriculture in Bangladesh is characterized by intensive crop production, mainly rice (*Oryza sativa*). The rice was planted in 11.7 million hectares of land in 2010-2011, producing 32.3 million m. tons (BBS, 2011). Rice contributes 91.12% of the total grain production and covers 68% of the total calorie intake of this country's people (MOA, 1996). The crop production in Bangladesh is dominated by intensive rice cropping covering about 80% of arable land & the most dominant cropping pattern is T.aman & Boro rice. Out of total rice production in this country about 8.83%, 48.46% & 42.71% comes from aus, aman & boro crops, respectively (BBS, 2008). Although, Bangladesh ranks 4th in the world both in acreage and production of rice (FAO, 2002), it ranks 39th in yield (IRRI, 1995). The average yield (3.44 t ha^{-1}) is quite low compared to other leading rice producing countries such as China, Korea, Japan and the USA where yield is 6.27, 6.31, 6.58 and 7.37 t ha^{-1} respectively (FAO, 2003).

The total production of rice in Bangladesh is not sufficient to feed her people. The urgent need in the crop sector of Bangladesh Agriculture at this moment is to produce more food to feed the country's ever growing population. To attain self-sufficiency in food, efforts must be made to enhance the yield per unit area and improve the quality of the produce. Targeting high yield with a higher cropping intensity is the most logical way to raise the total area from the total production from the limited land resource. The practice of intensive cropping with modern improved variety is a major endeavour of crop production in Bangladesh. This in turn causes a marked depletion of inherent reserves in soils.

Increasing cropping intensity with minimal & unbalanced use of fertilizers, virtually without replenishment of micronutrients & with little or no return of crop residues to soil has led to a serious depletion of nutrient reserve in Bangladesh soils. Nutrient stresses in Bangladesh soils are increasing day by day. Before 1980's deficiency of NPK was a major problem but there after NPK, deficiency along with secondary and micronutrients

(S and B) are frequently reported (Islam *et al.* 1995, Islam and Hossain,1998; Haque and Jahiruddin, 1999). Sulphur deficiency has been recognized in many areas of Bangladesh, It is noted that current intensive use of agricultural land for crop production has extended the sulfur deficient areas to about 80 % in the Northern region of Bangladesh (Khan, *et al.,* 2007). Boron deficiency is also reported on some soils and crops (Islam *et al.* 1997).

Sulphur is an essential plant nutrient and plays a vital role in the synthesis of amino acids (methionine, cystein and cystine), proteins, chlorophyll and certain vitamins (Havlin *et al.,* 2004; Tiwari & Gupta, 2006). It is also known to be involved in the metabolism of carbohydrates, proteins and oils, formation of cell wall and flavour imparting compounds (Marschner, 1995). Sulphur is the constituent of organic matter and also involves in many chemical processes. Plants absorb S mainly in the form of inorganic sulphate (SO_4^{2-}) ions through the roots, thus sulphate S must be present in soils in sufficient amount in order to meet crop S requirements (Brady & Weil, 2002). Insufficient availability of sulphur to crop plants not only declines their growth and yield but can also deteriorate nutritional quality of the produce (Hawkesford, 2000; Schonhof *et al.,* 2007).

The major causes of S deficiency in Bangladesh include intensive cropping with high yielding varieties of different crops, soils remaining water logged due to wet land rice culture, shifting toward virtually sulphur free fertilizer, depletion of soil organic matter through the removal of organic residues from the field and loss of S by leaching in light textured soils in high rainfall areas (Islam *et al.*, 2009). Sulphur deficiency in crops results in a reduction of leaf area, seed number, seed weight, delayed floral initiation and anthesis (Jamal *et al.*, 2005). It reduces growth rate and plant protein, chlorophyll content and photosynthetic CO_2 fixation (Tiwari *et al.*, 1994). Sulphur deficiency causes a reduction in the synthesis of nitrate reductase enzyme, resulting in the minimal supply of reduced nitrogen to the developing organs (Onkersingh and Nandlal, 1997). Nitrogen assimilation is hampered due to the inadequate supply of S containing amino acids and thus nitrogen uptake and translocation are impeded (Badruddin, 1999).

Boron is essential for plants and B availability in soil and irrigation water is an important determinant of agricultural production (Tanaka and Fujiwara, 2007). Boron is directly or indirectly involved in several physiological and biochemical processes during plant growth. It is involved in the synthesis and metabolism of protein, maintaining the correct water relations within the plant, synthesis of adenosine triphosphate (ATP), translocation of sugar, fruiting process, growth of pollen tube and development of the flowering and fruiting stages (Bolanos *et al.*, 2004)

Among the micronutrients boron has been reported to be deficient in some soil of Bangladesh (Jahiruddin *et al.*, 1995). Approximately, 1 million hectare of cultivable land in Bangladesh is suspected to have boron deficiency problem (Ahmed and Hossain, 1997). Boron deficiency causes great depreciation in grain set & results in severe yield reduction in many of the world's grain producing countries (Rerkasem *et al*, 2004). Rice plant is sensitive to B deficiency especially at the panicle formation stage & insufficient boron application may lead to failure in panicle formation (Dobbermann & Fairhurst, 2000).

Nutrient content of grain is markedly improved due to application of S and B (Rahman *et al.*, 2008). The crop growth rate, relative growth rate, net assimilation rate, specific leaf weight and apparent translocation rate improved due to application of S and B (Smeia, 2006). Sulphur improves the nutritional value of rice. Sulphur increases the nitrogen-use-efficiency and has positive effects on yield formation. Boron improves the stability of rice plants because of its important role for cell wall synthesis as well as for carbohydrate metabolism. (Abul *et al.*, 2008).

Though a number of research works have been done on the effect of sulphur and boron on the yield and yield components of some crops but the effects of these elements on the chemical parameters of rice are yet to be reported. Keeping this in view, the present investigation was carried out with the following objectives :

- To study the effect of sulphur and boron on growth and yield of rice,
- To determine the appropriate dose of sulphur and boron fertilizers for satisfactory rice yield and
- To evaluate the effect of sulphur and boron fertilizers on nutrient content of rice.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Rice (*Oryza sativa*) is interwoven with Bangali culture. It is symbol of wealth. The Food Department of the Government of Bangladesh recommends 410 gm of rice $head^{-1}$ day^{-1} (Banglapedia, 2003). The significance of macro and micro nutrients such as sulphur and boron nutrition is well established. Numerous works have been done on the effect of sulphur and boron with and without macro and micro nutrients. But information concerning their effect on rice under the climatic condition of Bangladesh is meager. An attempt has been made to review some of the available literatures pertinent to the present study in this chapter.

2.1 Sulphur in Agriculture

2.1.1 Sulphur status in soil

Sulphur occurs in soils in organic and inorganic forms, with the organic S accounting for >95% of the total S in most soils from humid and semi-humid regions. Total S in mineral soil may range from <20 μg g^{-1} in sandy soils to >600 μg g^{-1} in heavy texture soil (Khan, 2000). Organic soil may contain as much as 0.5% S. most soils, however, contain 100 to 500 μg g^{-1} S in soil (Setia *et al*., 2005). Variable amount of available S ranging from as low as 2 μg g^{-1} soil to as high as 75μg g^{-1}soil has been reported in Bangladesh soil (Islam, 2009).

2.1.2 Extent of sulphur deficiency in soil

Sulphur is considered as one of the most limiting nutrients in Bangladesh agriculture in the rice fields. S deficiency problems appear more often (Hitsuda *et. al*., 2005). According to estimates of The Sulphur Institute (TSI) based on crop demand, fertilizer efficiency and current inputs, the current S deficit is about 9.6 million ton annually. It is noted that about 7 M ha (about 52 %) of agricultural lands are reported to consists of sulfur deficient soils in the northern region of Bangladesh (SRDI, 1999). The current intensive use of agricultural land for crop production has extended the sulfur deficient areas to about 80 % in the Northern region of Bangladesh (Khan *et al.*, 2007).

The highest levels of S deficiency are found in wetlands, mainly in soils containing acid-sulfate materials, and in alkaline, gypsiferous soils in arid and semiarid regions (Ribeiro, *et. al.*, 2001).

2.1.3 Symptoms of sulphur deficiency in plant

Sulphur deficiency symptoms vary between crops. Symptoms of sulphur deficiency in crops include leaf cupping, purling undeveloped pods, stunted, thin spindly plants, slow growth, delay maturity, initial light green of leaves progressing to yellow leaves and in severe cases, the whole plant becomes yellowish, crops may lose their natural colors (Tisdale *et al.*, 1999). Recently, sulphur deficiencies in rice fields have been reported in different areas of Bangladesh. Sulphur deficiency in rice is often confused with nitrogen deficiency. In the early season, S deficiency shows as a yellowing of the new leaves, while N deficiency develops first in the older leaves. Later, brown spots begin to appear on the upper leaves. These spots may be confused with the rice disease brown spot. However, sulfur-deficient spots are found in rows corresponding to the leaf veins. Brown spots from disease are randomly distributed on the leaf surface (Rahman *et al.*, 2007). The effect of S deficiency on rice yield is more pronounced during vegetative growth e.g. reduced plant height and stunted growth, reduced number of tillers, fewer and shorter panicles, reduced number of spikelets panicle^{-1} etc. Evidence showed that rice soils of Bangladesh are becoming deficient in S day by day. Use of high analysis S-free fertilizers such as urea, triple super phosphate, muriate of potash and flooding of land causing S in reduced condition for a considerable period of time result in decreased available S in soil for crops.(Ali *et al.*, 2004).

2.1.4 Critical levels of sulphur in soil and plant

The critical level of sulfur for Bangladesh soils has been determined as 10 µg g^{-1}soil (Hasnat *et al.*, 2008). Sulphur requirement for optimal growth varies between 0.1 and 6% on dry weight basis of plants and it increases in the order of gramineae < leguminosae < cruciferae (Dekok *et al.*, 2002). Huda *et al.*, (2004) evaluated that critical limit of S in rice soil is 0.12% at 56 days of crop growth. Based on dry weight, the S concentration of most soil microorganisms is ranges between1 and 10µg g^{-1}, the C:S ratio between 57:1 and 85:1 and the N:S ratio is about 10:1 (Jamal *et al.*, 2006).

The critical limit of MCP, 0.15% $CaCl_2$, 0.5 M $NaHCO_3$ and 0.5 M NH_4OAc extractable S were about 9.3, 9.7, 15.8 and 17.8 mg kg^{-1}, respectively in both graphical and statistical methods for rice. The critical S levels in leaf tissues were 0.17% for rice, 0.20% for maize and wheat, 0.22% for chickpea and 0.25% for mustard and peanut (Huda *et al.*, 2004).

2.1.5 Role of sulphur in plant

Sulphur is essential for plant development and growth, sulphur performs many important functions in the plant. It is best known for its role in the synthesis of proteins, oils and vitamins. It is a constituent of three amino acids which are methionine (21% S), cysteine (26% S) and cystine (27% S) involved in chlorophyll production and is thus required for protein synthesis and plant functions and structure (Hegde and Babu, 2007). Cystine is formed by the oxidation of two molecules of cysteine (Naresh and Jangra, 2007). Sulphur is also a constituent of S-glycosides, co-enzyme A, vitamins viz. biotin and thiamine, cofactors S adenosyl-L-methionine, molybdenum cofactor (MoCo), and lipoic acid, the chloroplast lipid sufloquinovosyl diacylglycerol, iron sulphur proteins called ferrodoxines and many secondary compounds (Leustek, 2002; Matsubayashi *et al.*, 2002).

Sulphur containing amino acids is also important intermediates in synthesis of other compounds within the cell. For example, S adenosyl methionine serves as a methyl donor in biosynthesis of many cellular components including chlorophyll, flavonoids and sterols. Sulphur is needed for the synthesis of coenzyme A, which is involved in the oxidation and synthesis of fatty acids, the synthesis of amino acids (Scherer, 2009). Sulphur is known to stimulate root growth, seed and nodule formation (Saito, 2000). Sulphur is also major components of ferredoxin the electron transfer molecule involved in photosynthesis and in reduction of oxidized compounds such as nitrite. Plant membrane structure and function also require S, sulpholipids being essential membrane compounds and intimately involved in organization of chlorophyll in chloroplast lamellae. Flavors, odors and toxic agents in some plants can be linked to a range of S containing compounds (Scherer, 2001). Plant metabolism depends on S and that S deprivation will cause basic metabolic dysfunction, which will result in reductions in crop yield and quality.

Sulphur fertilization is useful not only in increasing crop production and protein content, but also in improving soil conditions for crop growth. Sulphur is associated with the production of crops of superior nutritional and market quality (Samaraweera, 2009). Sulphur is an integral component of certain vitamins and enzymes. The addition of S fertilizer provides enough S for the plant to synthesize required amounts of the S-containing amino acids, thus producing a greater amount of protein (Chandel *et al.*, 2003). This author maintained that careful management of the fertilizer programme, including balanced application of S and B, are required to ensure optimal yields and nutrient contents.

2.1.6 Effect of Sulphur on yield and yield attributing characters of rice

Mandal *et al.*, (2000) carried out a greenhouse experiment to evaluate the effect of N fertilizer on nutrients 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 ha^{-1}. The combined application of two elements increased the straw S content only at tillering stages. The uptake of nutrient in straw was improved significantly, which was reflected in the grain yields.

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

Sakal *et al.*, (2001) carried out field experiments in 4 villages selected in Saharsa district in Bihar, India to determine the direct effect of soil applied with sulfur on succeeding wheat and rice crops. Sulphur was applied at 0, 15, 30 and 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 uptake by crops progressively increased with increasing levels of sulphur.

Subbaiah *et al.,* (2001) conducted muti-locational trials using different sulphur sources(single superphosphate, pyrite, gypsum, elemental sulphur and ammonium sulphate) on rice at Pusa and Patana (Bihar); Kharagpur (WB); and Balagarh (MP). Results of the experiments clearly indicated that continuous application of diammonium phosphate in conjunction with sulphur containing fertilizers improved grain yield in low land ecosystem. On the basis of mean of two years data, maximum grain yield of 4.17 t ha^{-1} was recorded by the treatment receiving recommended NPK + 20 kg S ha^{-1} as pyrite, which was followed by the treatment receiving NPK + 20 kg S per ha as elemental sulphur.

Yang *et al.*, (2000) studied the effects of sulphur and nitrogen fertilizer with rice cv. Weiyou 63 in Fijians, China and found that S fertilizer treated plots (6.9 mg available S kg^{-1} soil), with 120 and 140 kg N ha^{-1}, plants without S fertilizer treatment. On the other hand N and S treated plots (received N rate of 0,150 and 210 kg ha^{-1} and S rates of 0, 30 and 60 kg ha^{-1}) produced the highest yield 8850 kg ha^{-1} with 150 kg N ha^{-1} + 60 kg S ha^{-1}. Moreover, they stated that the optimum ratio for N: S fertilizer was 4:1.

Shen *et al.*, (2002) carried out an extensive study on application of sulphur through single superphosphate in a sulphur deficient area of Murshidabad district 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 helped not only to increase yield in both the crops but also to control the movement and distribution of different cationic micronutrients in both the crops.

Babu and Hedge (2002) carried out field studies in Andhra Pradesh, India to evaluate the direct and residual response of sulphur on rice-sunflower cropping system. The direct effect of sulphur through single superphosphate on hybrid rice resulted in a significant increase of 21% in grain yield with S use efficiency of 13 kg grain ha^{-1} and 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 yield. The valued cost ratio (VCR) for direct and residual effects was 35 and 23 with a cropping system VCR of 58.

Sing and Sing (2002) conducted a field experiment with different levels of nitrogen and sulphur on the yield of rice cultivars (Swarna and PR-108). Result showed that the total nitrogen uptake, grain and yield significantly improved with increasing levels of nitrogen and sulphur application being the maximum at 150 kg N ha^{-1} and 40 kg S ha^{-1} respectively.

Xue *et al.*, (2002) showed that rice yield increases due to S application ranged from 0.5 to 22.9% (average of 7.3%) or from 15 to 35 kg ha^{-1} (average of 15 kg ha^{-1}). Sulfur at 15-30 kg ha^{-1} was optimum for rice production.

Chandel *et al.*, (2003) conducted a study to see the effect of sulphur nutrient on growth and sulphur content in rice and mustard grown in sequence. The experiment was laid out in split plot design with four sulphur levels (0, 15, 30 and 45 kg ha^{-1}) applied to rice as main plot treatments during rainy season and each plot further divided into three subplots (0, 20 and 40 kg S ha^{-1}) applied to mustard during winter season. They found that increasing sulphur levels in rice significantly improved leaf area index, tiller number, dry matter production, harvest index and sulphur content in rice up to 45 kg S ha^{-1} .

Oliveira *et al.*, (2003) studied the effect of the rage of gypsum in granular and powder forms, on two rice cultivars on red Latosol (Hapludox) under greenhouse conditions. Sulphur rates were 0, 1, 2, 5 and 10 mg/dm^{-3} of soil from four standard sources. They observed that powder oxysulphate in IAC 165 and granular oxysulphate in IAC 202 resulted in grain yield similar to those obtained with sulphate used as the control. They found that IAC 202 was more efficient in sulphur utilization for vegetative growth and grain yield.

Dewal and Pareek (2004) reported that successive increase in sulphur levels up to 40kg per ha significantly improved effective tillers, grains per spike, spike length and grain, straw and biological yields of rice.

Sriramchandrasekharan *et al.*, (2004) conducted a field trial in a S-deficient clay loam (Typic Haplustert) and sandy clay loam soil (Typic Ustiflivents) in Tamilnadu, India to evaluate the response of 10 rice genotypes (ADT 36, ADT 37, ADT 38, ADT 39, ADT

42, ADT 43, CO 43, ASD 19, CO45 and CO47) to different levels of S applied through gypsum (0, 20 and 40 kg ha^{-1}). Application of S increased grain yield in all genotypes. The highest yield was obtained with 40 kg S ha^{-1} (14.8% over the control). On the basis of Bray's percent yield response, CO 47 was considered as highly tolerant and ASD the least tolerant to S stress and other genotypes were intermediate.

Haque and Chowdhury (2004) observed that dry matter yield of rice plants significantly increased at both maximum tillering and panicle initiation stages after treatment with rice straw and S applied together. There were significant increases in all yield contributing attributes of the crop except, 1000-grain weight in both rice straw and S treatments over control. Grain and straw yields of rice significantly increased due to application of rice straw and S together over control treatment. Grain yield increases were 11.90, 19.76 and 25.95% in rice straw, S and rice straw and S (together) treatments respectively over the control treatment.

Issa and Sharma (2006) conducted a field experiment at the Indian Agricultural Research Institute, New Delhi, to study the effect of sulphur on yield attributes and yield of rice. Yield attributes, straw yields and protein content increased significantly with increasing level of sulphur up to highest level of 45 kg S ha^{-1}

Jena *et al.,* (2006) stated that application of gypsum at the rate of 60 kg S ha^{-1} to groundnut-rice cropping system recorded highest cumulative grain yield. lowest pod yield of 9.0 q ha^{-1} was recorded in control whereas highest pod yield of 18.5 q ha^{-1} was obtained with the application of gypsum at the rate of 60 kg S ha^{-1} which was significantly different from all other treatments but was at par with the application of S-95 at the rate of 60 kg S ha^{-1}. Residual effect S application was evident up to 60 kg S ha^{-1} with S-95 and gypsum on rice. The maximum rice grain yield was 39.0 q ha^{-1} with S-95 at the rate of 60 kg Sha^{-1} which was at par with gypsum at the rate of 60 kg S ha^{-1} over the control.

Sreedevi *et al.,* (2006) conducted a field experiments in Hyderabad during wet and dry seasons of 1997-98 to find out the effect of different rates of sulfur on yield with 6 different rice cultivars. Pooled analysis of data showed that application sulfur at the rate of 20 kg ha^{-1} for hybrids produced better yield, while for conventional high yielding varieties 40 kg ha^{1} found to be superior.

Vyas *et al.*, (2006) conducted a field experiment at National Research Centre for rice, under rain-fed conditions to investigate the productivity of rice genotypes as influenced by nitrogen and sulphur nutrition. Results revealed that basal application of sulphur at the rate of 40 kg ha^{-1} increased the yield by 21.8% over basal application of N at the rate of 20 kg ha^{-1}. Application of 20 kg N + 40 kg S per ha as basal produced the maximum grain yield.

Basumatary and Talukdar (2007) conducted a field experiment during 2002-2004 at the University, Jorhat, Assam, India to find out the direct effect of sulfur alone and in combination with graded doses of farmyard manure on rapeseed and its residual effects on rice with respect to yield, uptake and protein content. The N: S ratio in both crops progressively decreased with increasing sulfur levels up to 45 kg S ha^{-1}. The lowest N: S ratio was observed upon treatment with 45 kg S ha^{-1} along with 3.0 t farmyard manure ha^{-1}.

Bhuvaneswari *et al.*, (2007) conducted a field experiments during the 2001 to study the effect of sulfur at varying rates, i.e. 0, 20, 40 and 60 kg S ha^{-1}, with different organics, i.e. green manure, farmyard manure, sulfitation press mud and lignite fly ash, each applied at 12.5 t ha^{-1} on yield, S use efficiency and S optimization of rice cv. ADT 43. The results revealed that rice responded significantly to the application of S and organics compared to the control. The highest grain (5065 kg ha^{-1}) and straw yields (7524 kg ha^{-1}) was obtained with 40 kg S ha^{-1}.

Oo *et al.*, (2007) conducted a field experiment during the rainy season of 2003 at the research farm of the Indian Agricultural Research Institute, New Delhi to study the effect of N and S levels on the productivity and nutrient uptake of rice. They observed that rice requires 100 kg N ha^{-1} and 20 kg S ha^{-1} for increased productivity and uptake of N, P, K and S under transplanted puddle conditions. Treatments comprised : 4 N levels (0, 50, 100 and 150 kg ha^{-1}) and 4 S levels (0, 20, 40 and 60 kg ha^{-1}).

Dinesh *et al.*, (2007) conducted a field experiment during rainy season of 2003 at the research farm of the Indian Agricultural Research Institute, New Delhi to study the effect of N and S levels on productivity and nutrient uptake in aromatic rice. The experiment was carried out with 16 treatments combinations of 4 N levels (0, 50, 100 and 150 kg/ha) and 4 S levels (0, 20, 40 and 60 kg/ha) in factorial randomized block design replicated thrice. Growth and yield attributes, grain, straw and biological yields increased significantly with N and S levels. The increase in grain yield due to application of 100 and 150 kg N/ha over control was 1.99 t S ha^{-1} and 1.95 t S ha^{-1} and in terms of percentage increase was 49.5 and 48.5% respectively. The percentages increase in the grain yield of rice at application of 20, 40 and 60 kg S ha^{-1} over the control were in the order of 6.5,7.3 and 8.8% respectively. Various N and S levels had a significant effect on N, P, K and S uptake by grain, straw and their total.

Mrinal and Sharma (2008) conducted a field trials during the rainy season of 2002 and 2003 to study the relative efficiency of different sources (gypsum, elemental sulfur and cosavet) and varying levels of sulfur (0, 10, 20, 30 and 40 kg S ha^{-1}) in rice. The growth and yield attributing characters of rice increased with the sulfur application. The grain and straw yields of rice increased significantly with increasing levels of sulfur up to 30 kg S ha^{-1}. The difference between sulfur sources was generally not significant.

Islam *et al.,* (2009) conducted a field experiment in the farm of Bangladesh Agricultural University (BAU), Mymensingh during T. aman season of 2006 to evaluate the effects of different rates and sources of sulphur on the growth and yield (cv. BRRI dhan30). There were seven treatments consisting of four levels of sulphur (0, 8, 12 and 16 kg S ha^{-1}) applied as either SSP (Single Superphosphate) or gypsum. All plots received 100 kg N, 20 kg P, 60 kg K and 2 kg Zn ha^{-1} from Urea, TSP, MOP and ZnO, respectively. The grain and straw yields as well as the other yield contributing characters like effective tillers $hill^{-1}$, panicle length, filled grains $panicle^{-1}$ and 1000 grain weight were significantly influenced due to application of sulphur. The highest grain yield of 5293 kg ha^{-1} and straw yield of 6380 kg ha^{-1} were obtained from 16 kg S ha^{-1} applied as gypsum. The lowest grain yield (4200 kg ha^{-1}) and straw yield (4963 kg ha^{-1}) were recorded with S control treatment. The overall results suggest that application of sulphur @ 16 kg S ha^{-1} as gypsum was the best treatment for obtaining higher grain yield as well as straw yield of T. aman rice.

2.1.7 Effect of sulphur on nutrient content of rice.

Sakal *et al*., (1999) reported that the optimum level of S for rice and wheat appeared at 40 and 60 kg S ha^{-1} respectively. The grain yield response at optimum S level in rice was 871 kg ha^{-1} and in wheat it was 659 kg ha^{-1}. Sulphur application showed a synergistic effect on N and an antagonistic effect on P and K content in rice. The optimum N:S ratio was 17.8 and 6.7 respectively. Protein content in rice and wheat grain was increased from 7.93 to 9.23% and 12.11 to 14.09% respectively at their optimum S levels.

Abraham (2000) conducted an experiment with different treatment combinations of 20 or 40 kg S and 100 or 150 kg N ha^{-1}, and reported that soluble protein content and rate of photosynthesis were the highest with 40 kg S + 100 kg N ha^{-1} . Since S is an important component of protein, balanced N:S fertilization was important in obtaining optimal yields. If the N:S ratio was too great, protein synthesis might be restricted and N might accumulate in the plant in non-protein forms.

Li-Yu and Li (2000) conducted a field experiment on meadow black soils. Rice was given NPK alone (control) or in combination with S at different application rates. Sulfate or S increased rice yield by 28.8% and 19.7% respectively and also increased seed quality and starch content.

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 sulphur rates up to 40 kg ha^{-1} and then decreased slightly.

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

Sarfaraz *et al.*, (2002) conducted a field experiment with different sulphur fertilizers and NPK fertilizers on the yield and chemical composition of rice (cv. Shabeen basmati). Result showed that sulphur fertilizers increased sulphur content and its uptake in straw compared to NPK treatment.

Ali *et al.*, (2004) observed that the dry matter yield of rice plant at maximum tillering stage, grain yield were significantly increased due to application of sulphur. Nutrient content and uptake by rice plant was statistically significant due to application of sulphur. They also observed that N uptake by rice plant increased with increasing levels of S. Sulphur also increased K content (28.11 kg ha^{-1}) of rice plant.

Islam *et al.*, (2006) an experiment was conducted in Bangladesh to evaluate the effect of gypsum (100 kg ha^{-1}) applied before planting, and at 30 and 60 days after planting on the nutrient content of T. aman rice in the presence of basal doses of N, P,K fertilizers. Application of gypsum at different dates increased progressively all the nutrients such as N, P, K, S, Ca and Mg, whereas the Na content was found to decreased due to gypsum application. The highest increase of N, P, K, S, Ca and Mg was obtained when the gypsum was applied at 30 days after planting. Synthesis of protein was accelerated with all the treatments of gypsum and the content was much higher due to application of gypsum at 30 days after planting.

Alam *et al.*, (2007) conducted a field experiment of BAU farm, Mymensingh of 2004. There were five treatments viz. T_0 (control), T_1 (10 kgSha^{-1}), T_2 (20 kg Sha^{-1}), T_3 (40 kg Sha^{-1}) and T_4 (60 kg Sha^{-1}). They observed that the highest N, P, K and protein content was recorded from treatment T_2 (20 kg Sha^{-1}). On the other hand, the highest S, Ca and Mg content was recorded from treatment T_4 (60 kg Sha^{-1}). However, the application of S fertilizer significantly increased protein, N, P, K, S, Ca and Mg content as well as their uptake over control. The S balance was positive where S was added as treatment combination. Negative S balance was recorded where no S was added (control).

Alamdari *et al.*, (2007) conducted a field experiments to study the effect of sulfur and sulfate fertilizers on zinc (Zn) and copper (Cu) by rice. The maximum Cu content in the leaves was attained when N, P, K, S and Cu sulfate were applied compared to the control.

But both Zn and Cu contents in the grain increased when N, P, K, S and Zn, Cu and Mn sulfate were applied together.

Nawmarlar *et al.,* (2007) reported that a significant effect of sulphur application on N, P, K and S uptake in rice grown in a field experiment at IARI, Delhi.

Rahman *et al.,* (2007) conducted a field experiment on a Non-Calcareous Dark Gray Floodplain Soil (Sonatola series) of BAU farm, Mymensingh in 2004. The experiment was laid out in randomized complete block design with four replications and five treatments viz. T_0 (control), T_1 (10 kg S ha-^{1}), T_2 (20 kg S ha $^{-1}$), T_3 (40 kg S ha $^{-1}$) and T_4 (60 kg S ha $^{-1}$). The highest N, P, K and protein content was recorded from treatment T_2 (20 kg S ha $^{-1}$). On the other hand, the highest S, Ca and Mg content was recorded from treatment T4 (60 kg S ha $^{-1}$). However, the application of S fertilizer significantly increased protein, N, P, K, S, Ca and Mg content as well as their uptake over control. The S balance was positive where S was added as treatment combination. Negative S balance was recorded where no S was added (control).

Islam *et al.*, (2009) reported that application of sulphur significantly increased N, P, K and S uptake in rice plant. They suggested that application of sulphur @ 16 kg S ha^{-1} as gypsum was the best treatment for obtaining higher grain yield as well as straw yield of T. aman rice.

Okuda *et al*., (2009) investigated that the influence of nitrogen and sulfur compounds in rice grains on changes in flavor in stored sake. Nitrogen content exhibited a significant positive correlation with sulfur content. Based on the molar ratio of nitrogen to sulfur in the rice grain, the sulfur compounds appeared to be derived from protein-associated sulfur-containing amino acids. The higher the protein content of the rice, the greater the amount of nitrogen and sulfur compounds found in both the digest of steamed rice grains and in the sake. Physicochemical changes were investigated in the stored sake to confirm the influence of total sulfur content. Polysulfides in the stored sake appeared to be higher when made from rice grains of high total sulfur content. Staling of stored sake was affected by levels of protein-associated sulfur-containing amino acids in the rice.

Samaraweera (2009) reported that the application of 50.0 kg sulphur per ha through Factomphos increased N, P, S and Zn content and N, P, K, S, Zn, Cu, Fe and Mn uptake by rice and it was on par with the application of 37.5 kg sulphur per ha through Factomphos.

Shamim *et al.*, (2009) carried out a field experiment to evaluate the effectiveness of sulficide materials (SM) and gypsum application at the rates of 0, 20, 30, 40, 50 and 60 kg S ha^{-1} on the N, P,K, Mg and S nutrient in rice (*Oryza sativa* L.). They observed that the contents of N, P, K, Mg and S nutrient in rice shoots at different growth stages of rice were increased by the application of SM and gypsum fertilizer.

2.2 Boron in Agriculture

2.2.1 Boron status in soil

Boron is very water soluble and is mobile in soil water solution. The total concentration of B in soils varies between 2 and 200 µg g^{-1} and frequently ranges from 7 to 80 µg g^{-1}. Less than 5% of total soil B is available to plants. Plants absorb B principally in the form of H_3BO_3 (Tariq *et al.*, 2005) and this form of boron is highly mobile in the soil (Robertson *et al.*, 1997) and to a smaller extent as $B_4O_7^{2-}$, $H_2BO_3^{1-}$, HBO_3^{2-} and BO_3^{3-} .Tourmaline is the main B containing mineral found in the soils, which is insoluble and very resistant to chemical breakdown in the weathering; consequently, release of B is quite slow (Devirian and Volpe, 2003). Although, tourmaline is the chief source of boron (about 10% B), a considerable portion of the soils content of B is held in its organic matter, from which it is gradually released by soil microorganisms. Soil B is positively correlated with organic carbon content (Zhu and Liu, 1999). Organic matter is a major storehouse of available B for crop use and it also adsorbs boron (Yermiyahu *et al.*, 2001).

The inorganic forms in which B occurs in soils are chiefly borates of calcium, magnesium and sodium, which result from the slow dissolution of B containing minerals, mainly tourmaline (Zerrari *et al.*, 1999) Bangladesh Agricultural University Farm soil contain available boron 0.14 µg g^{-1} soil (Wadud, 2002).

2.2.2 Extent of boron deficiency in soil

Boron is recommended for responsive crops when the soil contains less than 1 $\mu g\ g^{-1}$. Boron deficiency occur more frequently in the humid regions of a country on highly leached acid sandy soils (low B reserves), alkaline soils or lime treated soils have reduce boron uptake due to high pH levels. Clay minerals as well as Al and Fe oxides absorbs B (Goldberg and Chuming, 2007). Approximately 1 million ha of cultivable land in Bangladesh is suspected to have B deficiency problem (Ahmed and Hossain, 1997). The severity of the deficiency depends on the low soil moisture, soil texture, soil pH and the time elapsed following liming (Saleem *et al.*, 2011).

2.2.3 Symptoms of boron deficiency in plant

Boron deficiency is the second most common and widespread micronutrient problem (Alloway, 2008). Deficiency symptoms vary between crop species, but generally occur in the growing points or flower and fruiting parts of the plant. It is characterized by abnormal or retarded elongation of apical meristems (Benton, 2003). Commonly occurring B deficiency symptoms include chlorosis and death of the growing points, distortion thickening and cracking of stems, formation of rosettes, growth of auxiliary buds, bushy growth and multiple branching (Anonymous, 2003). Root may become thick, twisted and do not develop properly, roots may show excessive branching, root crops often fail to develop edible portions or affected by the presence of dark colored corky areas, cuttings may fail to take root, the dropping of buds or blossom, fruits and seed may also be affected by developing of brown sunken areas on it (Dell and Huang, 1997).

Symptoms of B deficiency in rice are sometimes difficult to visually detect in the field (Gupta, 1999). Severe deficiency symptoms from rice include thinner stems, shorter and fewer tillers and failure to produce viable seed. Boron-deficient stems and leaves were found to be brittle while B-deficient leaves and stems are flaccid (Dunn *et al.*, 2005). B deficiency symptoms in rice plant results in white and rolled tips of emerging leaves, reduced plant height; severe deficiency can cause the death of growing point although new tillers continue to be produced. Boron deficiency at the panicle formation stage may fail to produce panicles (Dobbermann and Fairhurst, 2000).

2.2.4 Critical levels of boron in soil and plant

The B content in plants grown on normal soil is an indication of the B needs of the crop. Boron requirement of different plants is different. Rice cv. BRRI dhan 30 grain and straw normally contain 9 to 11 $\mu g\ g^{-1}$ B and 8 to 24 $\mu g\ g^{-1}$ B respectively (Kabir, 2003 and Wadud, 2002). Critical concentration of soil available B and plant tissues B was 0.30 ppm and 12.5 ppm, respectively and response of rice to boron application in B deficient soils was 61.53% (Debnath *et al.*, 2009).

The deficiency of boron is common throughout the world in all types of soils irrespective of textural class and is more pronounced in highly weathered soils and also under moisture stress condition. BARC (2000) reported that critical limit of soil boron 0.2, 0.16 and 0.2 $\mu g\ g^{-1}$ soil by cesium phosphate extraction for loamy to clayey soils of upland crops, sandy soils of uplands crops and loamy and clay soils of wetland rice, respectively. Plant species differ considerably in their boron requirement. Boron levels in rice plant tissue are considered deficient if concentration is < 5 mg kg^{-1}, sufficient if concentration is about 6-15 mg kg^{-1} and toxic if concentration is > 30 mg kg^{-1} (Dobbermann and Fairhurst, 2000). Average B content in most plants is 20 mg kg^{-1} on dry weight basis. Mortvedt and Woodruff (1995) reported the critical deficiency concentration of B to range 1 to 6mg kg^{-1} for monocotyledons species and 20 to 70 mg kg^{-1} for dicotyledons.

2.2.5 Role of boron in plant

Boron is essential micronutrient for plant growth & reproduction. It is essential for growth of new cells and proper development and differentiation of tissue. It helps in cell maturation by regulating the formation of lignifications of cell wall (Brady and Weil, 2002). Without adequate supply of B reduction in cell enlargement in growing tissues because of its structural role and responsible for creating male sterility and inducing floral abnormalities (Sharma, 2006).

Boron plays a vital role in the physiological processes of plants such as carbohydrate metabolism & translocation (Siddiky *et al.*, 2007), transport of sugars through membranes, nucleic acid (DNA and RNA) and phytohormone synthesis, formation of cells walls, tissue development etc. (Kabata and Pendias, 2001). Plants require B for synthesis of amino acids, proteins, nitrogen metabolism, root system development, nodule formation, increase pollination, fruit and seed development (Oosterhuis, 2001)

Boron has both direct and indirect effects on fertilization. Indirect effects are related to the increase in amount and change in sugar composition of the nectare whereby the flowers of species that rely on pollinating insects become more attractive to insects (Tariq and Mott, 2007). Direct effects of boron are reflected by the positive correlation between B in the plant and number of flowers, the proportion of flowers not aborted and fruit weight (O'Niell *et al.*, 2004). Moreover B stimulates germination, root elongation, IAA oxidase activity, sugar translocation, carbohydrate metabolism, nucleic acid synthesis, and pollen tube growth (Goldbach and Wimmer, 2007), plasmalemma-bound enzymes and ion fluxes across membranes (Goldbach *et al.*, 2001), cytoskeletal proteins (Yu *et al.*, 2003), accumulation of phenolics and polyamines (Camacho-Cristobal *et al.*, 2005) and nitrogen metabolism (Gonzalez-Fontes *et al.*, 2007)

The effect of boron on the development of the pollen grain of rice was studied by Rerkasem *et al.*, (2004). The process of fertilization involves the germination of the pollen grain and the growth of the pollen tube down the style into the ovary. In general, boron deficiency produces pollen grains that are small and that do not accumulate starch. Pollens that developed normally may still be affected by boron deficiency (Marschner, 1995)). Boron reduced panicle sterility and increased productive tillers per hill in rice. Post harvest grain shedding also reduced with improved B nutrition (Javaid *et al.*, 2011).

2.2.6 Effect of boron on yield and yield attributing characters of rice.

AARI (2000) reported that paddy yield increased significantly with Zn, Cu, B and Fe application @ 7.5, 5, 2.5 and 10 kg ha^{-1} respectively. Highest yield (5438 kg ha^{-1}) was obtained when all the micronutrients were applied along with NPK. The response to Zn, Fe, B and Cu remained significant over NPK. In another experiment higher yield (3737 kg ha^{-1}) with VCR 2.2 was produced where Zn and B was applied @ 5 kg and 1 kg ha^{-1} along with NPK where boron was applied @ 1, 2, 3 kg ha^{-1} along with N, P, K and Zn.

Dunn and Jones (2001) observed that increased rice yields over the untreated check. In 1999, the foliar applications produced higher yields than soil applied boron. The average for all four boron treatments in an application type was also greater in the foliar in the first year of the project. In 2000, the soil application for the same rate of fertilizer was greater. The same is also true for the 2000 average for the four treatments. The two year average, however, showed the soil applications produced greater yields for the same boron application rate. The 0.5 lb B acre ha^{-1} for both soil and foliar applications (170 bu acre ha^{-1}) showed the greatest increase compared to the untreated check (145 bu $acre^{-1}$).

Marchezan *et al*., (2001) carried out 3 years experiment on an albagualt soil to study the effect of micro-nutrient (trace element) application on irrigated rice. The complete treatment had the micronutrients boron (H_3B0_3), copper ($CuSO_4$). Iron ($FeSO_4$), manganese ($MnCl_2$), molybdenum (Na_2MoO_4) and zinc ($ZnSO_4$) and treatments in which each one of the micronutrients was omitted including a control without micronutrients and observed that leaf spraying application of micronutrients on leaves did not affect sees yield in any of the years in which the experiments were conducted.

Yang *et al.*, (2001) conducted field experiments for 3-4 years to evaluate the residual effect of boron (B) fertilizer for oil seed rape in an intensive crop rotation including two rice crops per year. Application of B fertilizer at rates of 1.1, 1.65 and 3.3 kg B ha^{-1} in the first year showed a different residual effect on oilseed yield in successive years, but had only small positive effect on the rice grain yield at two sites. The residual effect of 1.1 kg B ha^{-1} remained fully effective in correcting B deficiency in oilseed rape for 2 year in the inceptisols. Whereas the residual effect of 1.65 kg B ha^{-1} continued to correct B deficiency for at least 3 years in both the inceptisols and the ultisol.

Amitava *et al*., (2002) conducted an experiment in West Bengal, India to study the effect of B at (0, 0.25, 0.5 and 1 mg/kg) on the NPK uptake of rice cv. PD-4 was evaluated in acid alluvial soils (Dinhata, Barokodali, Punadibari, Coochbehar and Madhupur). Results showed that B up to 0.25 mg kg^{-1} increased dry matter yield and nutrient uptake.

Wadud (2002) studied the effect of Boron and Molybdenum on yield quality and nutrient uptake by rice cv. BRRI dhan 30. He observed that the number of effective tillers $hill^{-1}$, grain yield and biological yield was increased significantly and the best results were recorded in Boron 2 kg ha^{-1} + Mo 1 kg ha^{-1} treatment. The content o phosphorus varied. Significantly with the combined application of B Mo and it was found to be increased with increasing levels of B and Mo.

Hussain & Yasin (2004) conducted field experiments to study the residual effect of Zn and B in rice-wheat system. Wheat grain yield ranged from 3.45 to 3.53 t ha^{-1}. Highest yield was produced from 5kg Zn+2kg B ha^{-1}whereas, lowest yield was produced from control. Cumulative application of boron gave an increase of 10% over control; direct application gave an increase of 9% over control. However, residual effect of B increased paddy by 4% over control.

Dunn *et al*., (2005) studied the B fertilization of rice with soil and foliar application and observed that, rice receiving soil applied B produced (163.7 bu $acre^{-1}$) significantly greater yield than rice receiving foliar fertilized with B (153.5 bu $acre^{-1}$). In 1999 and 2001, rice yield from all B treatment rates was significantly greater than the untreated check. The 0.50 lb acre $^{-1}$ B rate produced the greatest yields (175 bu $acre^{-1}$). In 2001, the 10 lb $acre^{-1}$ B rate produced the highest yields (151.3 bu $acre^{-1}$).

Rashid (2006) reported that application of boron in rice reduces panicle sterility, attribute to better grain filling and uniform crop maturity, increased number of grain $panicle^{-1}$ and number of productive tiller $plant^{-1}$.

Rahmatullah *et al*., (2006) conducted a field experiment during 2004 - 05 on wheat and rice to study the response of boron application in wheat-rice system. Two levels of boron viz. 1 and 2 kg ha^{-1} with control were studied with the basal dose of N, P_2O_5 and K_2O as 120, 90 and 60 kg ha^{-1}. They observed that, the boron application significantly affected wheat grain yield that ranged from 2.70 to 3.49 t ha^{-1} given highest increase of 19.9% over control from 1.0 kg ha^{-1}. The number of tillers m^{-2}, spike m^{-2}, spike length, plant height and1000 grain weight of wheat were also significantly different from control for the same treatment. Paddy yield was also significantly affected by boron application, which ranged from 3.51 to 6.11 t ha^{-1}. The highest yield was obtained from 2 kg Bha^{-1} when applied to both crops. The number of spikes m^{-2}, number of spikes $plant^{-1}$, spike length, plant height and 1000 grain weight paddy were significantly affected over control. The direct application of 1 and 2 kg B ha^{-1} gave an increase of59.6 and 62.1%, cumulative application of 1 and 2 kg B ha^{-1} increased the paddy yield 61.1 and 74.1%, while residual application of 1 and 2 kg B ha^{-1} increased the yield by 36.8 and 48.8% over control. Boron concentration in the leaves of wheat and rice was significantly affected by the application of boron that ranged from 10.37 - 14.91 and 3.52 - 5.81 mg $kg^{-1,}$ respectively.

Kabir *et al.,* (2009) carried out a net house experiment to find out the effect of boron on growth and yield performances of rice (IRRI-11) grown on a loamy soil. Boron was applied at the rate of 0, 1, 2, 4 and 8 kg B ha^{-1}. Soil treated with boron showed a significant effect on the growth and yield of the crop. 2 kg B ha^{-1} produced the highest straw (10.01 g pot^{-1}) and grain (9.69 g pot^{-1}) yields and maximum uptake of N, P and K nutrients (193, 29 and 208 mg pot^{-1}) by the rice plants. The treatment (2 kg B ha^{-1}) increased about 139 and 149% more straw and grain, respectively over the control. The further increment in the dose of boron (i.e. 4 and 8 kg B ha^{-1}), however, reduced the growth and yield components of rice plant.

Ehsan *et al.*, (2009) investigated that the nutritional functions of boron in improving rice growth and yield. Three rice cultivars viz., KS-282 (salt-tolerant), BG-402-4 (mixed behavior) and IR-28 (salt-sensitive) of differential salinity tolerant were used to investigate the nutritional aspects of boron. Boron was applied @ 25, 50, 100, 200, 400 and 800 mg B ml^{-1}. Application of B improved all growth parameters i.e., tillering capacity, shoot and root length, and shoot and root weight. In shoot Na^+ and Cl^- decreased; whereas K^+ concentration and K^+: Na^+ ratio improved because of B supplied to saline medium. The highest improvement was recorded at 1.5kg B ha^{-1}in the saline and saline sodic soils. Nevertheless the highest B application @ 6 kg B ha^{-1} had shown an adverse affect on paddy and straw production in saline sodic soils in all the three cultivars as compared with all other B rates and control. The beneficial effect of B was due to reduced shoot Na^+ and Cl^- concentration and better ratio of K^+ and Na^+ in shoot.

Islam *et al.*, (2010) conducted a field experiment in the "Tista Meander Floodplain Soils" at BINA (Bangladesh Institute of Nuclear Agriculture) sub-station farm. Tajhat Rangpur to study the Effect of some secondary and micro nutrients along with organic amendments on T. aman. The doses of secondary, micro nutrients, PM and CD were 30 kg S ha^{-1}, 15 kg Mg ha^{-1} , 5 kg Zn ha^{-1}, 2 kg B ha^{-1}, 1.5 kg Mo ha^{-1}, 5 ton PM ha^{-1} and 5 ton CD ha^{-1}. The grain and straw yields of T. aman rice significantly influenced due to application of secondary nutrients, micronutrients and organic amendments though the different treatments were not prominent on panicle length. Grain yields of T. aman rice varied from 3410 kg to 3937 kg ha^{-1}.The overall results express that organic amendments with secondary and micro nutrients is essential to obtain satisfactory yield of T. aman in the experiment soil.

Javaid *et al.*, (2011) carried out a field experiment to determine the effect of different levels of boron on the yield and yield components of rice genotypes. Two rice varities viz., khushboo-95 and mehak were grown in field with four B levels 0, 0.5, 0.75 and 1.0 kg ha^{-1}. The application of boron at 0.5, .75 and 1.0 kg ha^{-1} enhanced the paddy yield of khushboo-95 by 9, 13, 19% and mehak by 7, 11 and 15% respectively over control. Boron application @ 0.75 and 1.0 kg ha^{-1} significantly enhanced the straw yield of khushboo-95, whereas the straw yield of mehak was significantly increased at 1.0 kg B ha^{-1}. Boron concentration in youngest fully developed levels of both varieties was significantly enhanced with each increment of applied B.

Mubshar *et al.*, (2012) conducted a field trial to evaluate the role of boron (B) application, at different growth stages, in improving the growth, yield and net economic return of rice during summer season, 2009. Boron was applied as soil application (at 1.5 kg ha^{-1} m^2) at the transplanting, tillering, flowering and grain formation stages of rice; nursery roots were dipped in 1.5% B solution before transplanting; and B was applied as foliar application (at 1.5% B solution) at the tillering, flowering and grain formation stages of rice, while control plots did not receive any B application. Boron application (except dipping of nursery roots in B solution, which caused toxicity and reduced the number of tillers and straw yield than control) substantially improved the rice growth and yield. Nonetheless soil application was better in improving the number of grains per panicle, 1000-grain weight, grain yield, harvest index, net economic income and ratio of benefit to cost compared with rest of the treatments. Overall, In conclusion, for improvement in rice performance and maximizing the net economic returns, the B may be applied as soil application at flowering.

2.2.7 Effect of boron on nutrient content of rice

Hossain *et al*., (1999) conducted experiment to observe the effect of B on the number of grain spike^{-1}, grain yield and grain nitrogen content in rice cultivars. They reported that N and B contents in grain were increased after addition of B to the soil indicating that B probably helped protein synthesis.

Rajinder *et al*., (1999) reported that the carbohydrate contents of the leaves, leaf sheaths and calms at harvest was reduced in treatments compared in the control, with application of boric acid at 0, 10, 20 and 30 ppm at panicle emergence and repeated after 10 days. The carbohydrate content of the panicle was increased by all the treatments. It is concluded that there is a synergistic interaction between K and B on the accumulation of carbohydrate and their partitioning to the panicle.

Sheudzhen *et al*., (1999) conducted a field trials with rice grown in soils treated with NPK and B and other trace elements. The effects of the trace elements on total protein and non-protein N contents in leaves + stems and in roots at tillering heading and the wax-ripe stage were studied in pot trials. Except for B, the trace elements increased total protein N contents in leaves + stems at the first 2 stages.

Xiong *et al*., (1999) reported that B or N significantly increased the nitrate reductase activity. There was a positive interaction between B and N.

Bellaloui *et al*., (2003) reported that the tolerance of crops to a shortage of boron in the soil varied markedly among species. This variation in tolerance was due, in part, too as β mannitol or β-sorbitol) which enhance the remobilization of B within the plant. Species lacking the capacity to form B-sugar alcohol complexes are intolerant of even short-term deficits in soil B supply.

Hosseini *et al*., (2005) found out that soil B application increased B, Cu, P and K concentrations, but reduced the concentrations of Fe.

Jana *et al.*, (2005) observed that the application of B increased NPK contents and uptake in rice grain.

Akram *et al*., (2006) reported that increasing supply of boron increased the accumulation of boron in roots and shoots. Increased B concentration up to 1.0 mg kg^{-1}in salt affected loamy soil resulted in an increased in the yield of rice grain.

Indira (2006) carried out a field experiment to observe the effect of micronutrients (Zn, B and Mn) alone or in combination on the yield, some yield attributes and nutrient uptake of rice. The highest value of yield, different yield attributes and uptake of nutrients were recorded in the plots receiving boron in combination with Mn and Zn. Application of Mn + B + Zn significantly increased no of grains/ear and 1000 grain weight by 29.39 and 16.60% respectively over control. Application of Mn + B + Zn to rice crop improved its seed and straw yield (47.59 and 47.43%) and N, P and K uptake (83.33, 92.68 and 95.27%) thus emphasizing the need for micronutrient application to rice and other crops.

Ghatak *et al.*, (2006) studied the effects of boron on the yield, and concentrations and uptake of N, P and K by rice in red and laterite soils of west Bengal, India, The application of boron significantly increased plant height, number of effective tillers, panicle length, number of grains $panicle^{-1}$, grain weight and grain and straw yields of rice, but had no significant effects on N, P and K concentrations and uptake.

Kabir (2003) studied the boron toxicity of irrigation water and its interaction with other nutrients in 3 varieties of rice. He observed that increasing levels of B contaminated irrigation water increased the N, K, Cu and Fe concentration and decreased the Ca, Mg, S and Mn concentration both in grain and straw. Phosphorus and Zinc concentrations in grain were decreased but increased in straw due to the higher level of B application.

Wrobel *et al.*, (2006) conducted a pot experiment in 2001-2003 at Jelch-Laskowice, Poland to investigate the effect of boron fertilizer application on rice grown in light soil, deficient in B and subjected to periodic drought stress. Deficient in available boron in the soil revealed deficient amounts of boron in rice grain, which decreased the quality of rice grain as foodstuff or fodder. Application of boron fertilizer increased the grain weight and straw yields of rice and its application to soil during tillering stage improved the parameters of the main yield components, thus increasing yield level and enriching the chemical composition of the rice grain.

Dewal and Pareek (2007) conducted a field experiment at Jobner, Rajasthan, India to study the effect of boron, sulfur and zinc on growth, yield and nutrient uptake of rice. They reported that nutrient uptake increased up to highest level of B and S, except that B uptake was reduced at highest level of Zinc and Zinc uptake was reduced at highest level of boron.

Xiaohe and Paul (2008) conducted a hydroponic experiment to study the optimum hydroponic solution of B concentration for rice. They applied B at 0, 0.05, 0.2, 1, 5, 10, 25, and 50 µm. They found that B deficiency occurred when there was <7.3 mg kg^{-1} B in the flag leaves, <3.6 mg kg^{-1} B in shoots, and <0.2 µm B in the nutrient solutions. Boron additions increased dry matter, plant height and transpirational flow. Thus, B uptake was against a concentration gradient and high B supply, and as other evidence indicated, at low B supply.

CHAPTER III

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the experimental aspect of the work followed in the study containing a brief description of site, soil, climate, crop, treatment land preparation, experimental design, transplanting of seedlings, fertilizer application, intercultural operations, harvesting, data recording and soil and plant analyses.

3.1 Description of the experimental site

3.1.1 Location of the experimental field

The experiment was carried out in a typical rice growing soil on the south west corner of the main farm of Sher-e-Bangla Agricultural University, Dhaka, during the period from 24^{th} July to 24^{th} November 2011.

3.1.2 Characteristics of the soil

The soil of the experimental field was silt loam in texture belonging to the agro-ecological zone of the Madhupur Tract (AEZ-28). The selected plot was medium high land that remained fallow during the previous summer. The physical and chemical characteristics of the soil were determined at the Agricultural Chemistry Laboratory, Sher-e-Bangla Agricultural University, Dhaka. The characteristics of the soil are shown in Table 3.1.

3.1.3 Climate

The climate of the experimental site is subtropical in nature, characterized by three distinct seasons. The monsoon, popularly known as rainy seasons which extends from May to October, the pre-monsoon period or hot season extends from March to April and the winter season from November to February. The experiment was carried out in aman season, extending from July to November. Details of the meteorological data in respect of air pressure, temperature, rainfall, relative humidity, dew point, wind speed, sunshine hours during the period of the experiment have been given in Appendix I.

Table 3.1 Morphological, physical and mechanical characteristics of the soil of the experimental area.

a) Morphological characteristics

Locality	South-west corner of the Farm Building, Sher-e-Bangla Agricultural University
Soil series	Tejgaon Series
General Soil type	Calcarious Dark Grey Flood Plain
Physiographic unit	Madhupur Tract
Topography	Medium High Land
Drainage	Adequate
Flood level	Above flood level
Climate	Humid, Sub-tropical
Vegetation	Cropped with rice, pulse, mustard and other vegetation

b) Physical characteristics

Depth in cm	Description
0-15 cm	The soil is soft and feels floury. It appears cloddy but readily broken. When pulverized the soil is light brownish in color when pulverized. The soil is light brownish in color when wet, it shows finger print when pressed with thumb.

c) Mechanical composition of soil

Constituents	**Percent**
Sand	30.56
Silt	37.26
Clay	32.15
Textural class	Silt loam

d) pH and chemical composition of the soil

Parameters	Content
pH	5.65
Organic carbon (%)	0.75
Organic matter (%)	1.18
Total N (%)	0.032
Available P (μg g^{-1})	19.85
Exchangeable K (me $100g^{-1}$ soil)	0.12
Exchangeable Ca (me $100g^{-1}$ soil)	5.03
Excangeable Mg (me $100g^{-1}$ soil)	2.32
Available S (μg g^{-1})	16
Available B (μg g^{-1})	0.013
Available Zn (μg g^{-1})	0.8

3.1.4 Test crop

A high yielding variety of rice cv. BRRI dhan 30 was taken as the test crop. This variety was developed by Bangladesh Rice Research Institute (BRRI) Joydebpur, Gazipur. This is a popular variety recommended only for transplant aman season in Bangladesh. The height of 30 days seedlings ranges from 30 to 35 cm and of mature plant is about 120 cm, and the weight of thousand seed is about 22 g. This variety is somewhat resistant to pest and diseases particularly tungro, stem rot and leaf blight. The life cycle of this variety is completed within 115-120 days after transplant.

3.1.5 Land preparation

The land preparation was started one month prior to transplant of the seedlings. The land was thoroughly prepared with the help of a power tiller. Subsequently the land was sufficiently irrigated and ploughed and crops ploughed three times with country plough followed by laddering to have a good tilt. All kinds of weed, stubbles and residues of previous crop were removed from the field. After uniformly leveling, the experimental plots were laid out according to the requirement of the treatments and statistical design.

3.1.6 Experimental design

The experimental was laid out in a Randomized Completely Block Design (RCBD) with three replications having 16 treatment combinations. Thus the total number of unit plots was 48. The size of unit plot was 4 m^2 (2 m × 2 m). The plot to plot distance was 1 m and between block was 1 m. The treatments were randomly distributed to the plots within a block with proper fertilization. The bunds around individual plots were sufficiently strong to control water movement between plots. A drain of 1 m wide was provided around the whole experimental plot and between the blocks. The complete lay-out of the experiment has been presented in Figure 3.1.

3.1.7 Treatments

There were 16 treatments consisting of sulfur and boron including control. Sulfur was used as gypsum ($CaSO_4.2\ H_2O$) and boron as borax ($Na_2B_4O_7.10\ H_2O$)

Treatments of Sulfur and Boron

Sulfur treatment	Boron treatment
S_0 = Control	B_0 = Control
S_1 = 8 kg S ha^{-1}	B_1 = 1 kg B ha^{-1}
S_2 = 12 kg S ha^{-1}	B_2 = 1.5 kg B ha^{-1}
S_3 = 16 kg S ha^{-1}	B_3 = 2 kg Bha^{-1}

Total length = 17 m

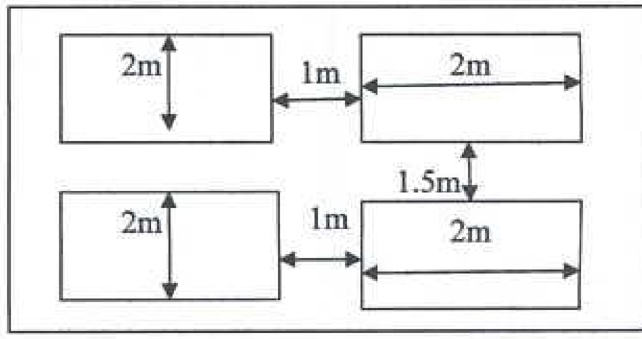
Total width = 21 m

Total area = 360 m^2

Distance between two blocks = 1 m

Distance between two plots = 1.5 m

Plot size = 2m × 2m



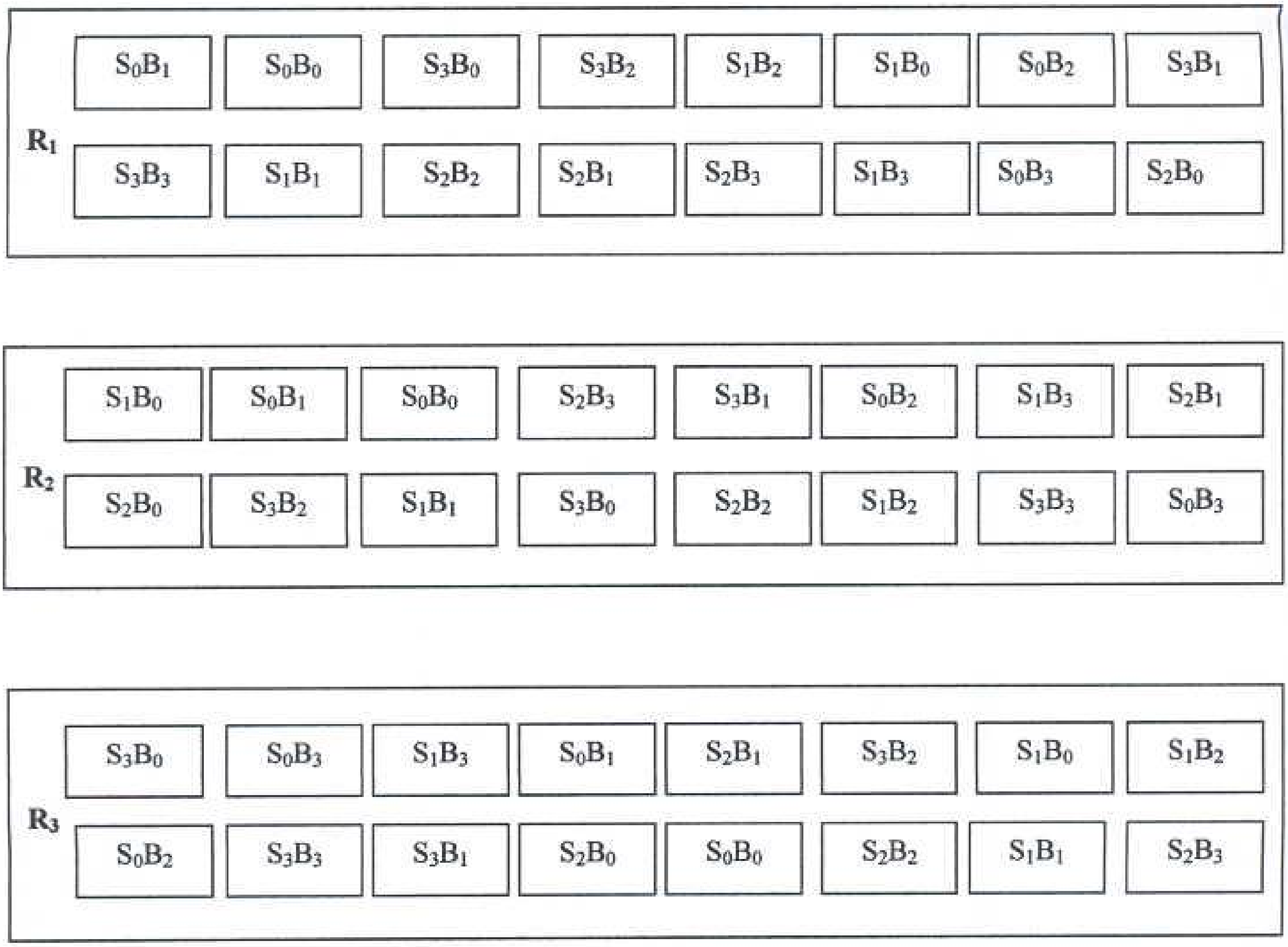


Figure 3.1 Layout of the experiment

The treatment combinations were as follows:

Treatments	Levels of Sulphur (kg ha^{-1})	Levels of Boron (kg ha^{-1})
S_0B_0	0	0
S_0B_1	0	1
S_0B_2	0	1.5
S_0B_3	0	2
S_1B_0	8	0
S_1B_1	8	1
S_1B_2	8	1.5
S_1B_3	8	2
S_2B_0	12	0
S_2B_1	12	1
S_2B_2	12	1.5
S_2B_3	12	2
S_3B_0	16	0
S_3B_1	16	1
S_3B_2	16	1.5
S_3B_3	16	2

3.1.8 Fertilizer application

The full amount of TSP, MOP, gypsum, borax and zinc sulphate were applied at the time of land preparation. Urea was applied in three equal splits, as top dressing first split 10 days after transplanting (DAT), second at active tillering stage at 30 days after transplanting (DAT) and third split at panicle initiation stage at 60 days after transplanting (DAT).

Fertilizers and their doses used in the experiment

Fertilizers	Fertilizer doses
Urea [CO $(NH_2)_2$]	120 kg ha^{-1}
TSP [Ca $(H_2PO_4)_2$ H_2O]	20 kg ha^{-1}
MOP [KCl]	50 kg ha^{-1}
Gypsum [$CaSO_4.H_2O$]	Treatment dose
Borax [$Na_2B_4O_7.10\ H_2O$]	Treatment dose
Zinc sulphate [$ZnSO_4.7H_2O$]	1 kg ha^{-1}

3.1.9 Transplanting of seedling

Thirty days old seedlings were collected from Sher-e-Bangla Agricultural University Farm, Dhaka and transplanted in the experiment field on 24th July, 2011 with a spacing of 15 cm from hill to hill and 25 cm from row to row. Three seedlings were transplanted in each hill. The number of rows and number of hills per rows were equal in all plots.

3.1.10 Intercultural operations

Intercultural operations were done in order to ensure and maintain the normal growth of the plants as and when needed. Following intercultural operations were done.

3.1.10.1 Irrigation

There was sufficient rainfall during the whole growing period. Yet, after transplanting four irrigations were needed to maintain 5-6 cm standing water in each plot throughout the growing period.

3.1.10.2 Weeding

The experimental plots were infested with some common weeds, which were removed by uprooting them from the field during the period of the experiment. Indeed three times weeding were needed.

3.1.10.3 Insect pest control

The field was infested by stem borer. To control the infestation insecticide Diazinon-60 EC at the rate of 2 ml L^{-1} water was applied.

3.1.11 Recording the data for plant height and tillers hill^{-1}

At 120 DAT (days after transplanting) plant height and tillers hill^{-1} were recorded from ten selected hills per plot and the average of plant height and tillers hill^{-1} was calculated.

3.1.12 Harvesting

The crop was harvested 24th November, 2011 at full maturity after 120 DAT. Ten hills from each plot were randomly selected to keep record on several plant characters. The harvested crop was threshed plot wise and sun dried. Sun dried weights of both grain and straw were duly recorded for each plot. The following data were collected and recorded.

1. Plant height
2. Effective tillers hill^{-1}
3. Non-effective tillers hill^{-1}
4. Panicle length
5. Filled grains panicle^{-1}
6. Unfilled grains panicle^{-1}
7. 1000- grain weight
8. Grain yield
9. Straw yield

3.2 Soil analysis

3.2.1 Collection and preparation of soil samples

The soil samples were collected at a depth of 0-15 cm from the experimental plots prior to addition of fertilizers. The pre planting soil samples were drawn by means of an auger from ten different random spots covering the whole experimental plot and were mixed thoroughly to make a composite sample. From the collected soil samples the stones, gravels, rabbles, plant roots, leaves etc were picked up, removed and sieved through a 10 mesh sieve. The soil samples were kept in a clean plastic container for physical and chemical analyses.

3.2.2 Soil pH

Soil pH was measured with the help of a glass electrode pH meter, the soil water ratio being maintained at 1:2.5 as described by Jackson (1973).

3.2.3 Textural class

Mechanical analysis of soil was done by hydrometer method as described by Piper (1966) and the textural class was determined by fitting the value for sand%, silt% and clay% to the textural triangle following USDA system.

3.2.4 Organic carbon and organic matter

Walkley and Blacks (1965) wet oxidation method was followed to determine the percentage of organic carbon as outlined by Jackson (1973). The underlying principle of the method is to oxidative organic matter with an excess of $K_2Cr_2O_7$ in presence of concentrated H_2SO_4 and to titrate the residual $K_2Cr_2O_7$ solution with 0.5N $FeSO_4$. The amount of organic carbon was multiplied by the conversional recovery factor of 1.724 to obtain the organic matter content.

3.2.5 Total nitrogen

Total nitrogen content of the soil sample was determined by macro Kjeldahl method by digestion with concentrated H_2SO_4 and digestion mixture (K_2SO_4: $CuSO_4.5H_2O$: Se = 10:1:0.1) and then distilled with 40% NaOH. The distilled ammonia was absorbed in boric acid in the receive in presence of mixed indicator (0.066 g methyl red + 0.99 g bromocresol green [$C_{21}H_{14}O_5Br_4S$] + 100 ml 95% methanol). Then it was titrated against 0.01N H_2SO_4 (PCARR, 1980).

3.2.6 Available phosphorus

Available phosphorus was extracted from the soil with 0.5M $NaHCO_3$ at a pH of 8.5. The phosphorus in the extract was then determined by developing the blue color by $SnCl_2$ which formed the phosphomolybdate complex and the color intensity was measured colorimetrically at 660 nm wavelength (Olsen *et al.*, 1954) with the help of a spectrophotometer.

3.2.7 Exchangeable potassium

Soil samples were extracted with 1N ammonium acetate (1N NH_4OAC, pH 7.0) and then exchangeable potassium content in the extract was determined by using flame photometer (Black, 1965).

3.2.8 Exchangeable calcium and magnesium

Exchangeable Ca and Mg of the soil samples was extracted by 1N NH_4OAC with pH 7.0 were determined by complexometric method of titration using Na_2EDTA ($Na_2H_2C_{10}H_{12}O_8N_2 . 2H_2O$) as a complexing agent as described by Page *et al.*, (1989).

3.2.9 Available sulphur

Available sulphur of soil samples was extracted by 0.15% $CaCl_2$ solution and determined turbidimetrically with the help of a spectrophotometer at a wavelength of 420 nm as described by Black (1965).

3.2.10 Available boron

Water soluble boron was extracted by hot water and determined by Azomethine-H method. Exactly 1mL of soil extract was taken in a polypropylene tube followed by the addition of 1 ml of buffer solution and 1mL of Azomethine-H reagent. Absorbance was read at 420 nm following the instruction of Page *et al.*, (1989).

3.2.11 Available zinc

Available zinc in soil was determined by DTPA extraction method. The extractable zinc was estimated directly by atomic absorption spectrophotometer .

3.3 Collection of plant sample

Ten hills were randomly selected from each plot, for collecting the following data:

3.3.1 Plant height

Plant height from ground level to the tip of the plant was recorded from 10 selected hills per plot in cm.

3.3.2 Number of effective tillers hill^{-1}

Number of effective tillers of the selected ten hills per plot was recorded then calculated the average.

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

The number of total tillers per hill was recorded from the randomly selected 10 hills per plot, and then calculated the average number of tiller.

3.3.4 Length of panicle

Length of panicles of ten selected hills per plot was recorded in cm.

3.3.5 Number of filled grains panicle^{-1}

The filled grains of each of the effective tiller for the individual plant and consequently those of all the selected ten plants were counted, the average of which gave the number of filled grain number per panicle.

3.3.6 Number of unfilled grains panicle^{-1}

The number of unfilled grain was counted from the randomly selected hills per plant, the average of which gave the number of unfilled grain.

3.3.7 1000-grain weight

1000-grain weight of the selected hills was recorded in gm after 4 sun drying and afterward it was adjusted at 14% moisture content.

3.3.8 Grain and straw yield

The total grain and straw weights were recorded per plot. After sun dry the weight of grains and straw also was recorded which was the yield of 2 ×2 m^2 and it was converted to yield per hectare.

3.4 Chemical Analysis of Grain and Straw

3.4.1 Preparation of sample

Both grain and straw samples were cleaned, oven dried at 65°C for about 48 hours . The oven dried materials were ground in a grinding machine and preserved in paper bags for chemical analyses.

3.4.2 Digestion of plant samples with nitric-perchloric acid

Exactly 1g of finely ground grain and straw materials were taken into a 250 mL conical flask and 10 mL of di-acid mixture (HNO_3: $HClO_4$ = 2:1) was added to it. Then it was placed on an electric hot plate for heating at 180-200°C until the solid particles disappeared and white fumes were evolved from the flask. Then it was cooled at room temperature, washed with distilled water and filtered into 100 mL volumetric flasks through Whatman No. 42 filter paper making the volume up to the mark with distilled water following wet oxidation method as described by Jackson (1973). This digestion was used for determination of P, K, S and B.

3.4.3 Digestion of plant samples with sulphuric acid

An amount of 1 gm oven dry, ground sample was taken in a 250 mL conical flask and 0.1 g catalyst mixture (K_2SO_4: $CuSO_4.5H_2O$: Se = 100:10:1). 2 mL 30% H_2O_2 & 3 mL 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.

3.4.4 Grain and straw analysis

The grain and straw samples were chemically analyzed for the following parameters:

3.4.5 Determination of total nitrogen

The total nitrogen content of the samples was determined by macro Kjeldhal method as described by Page *et al.,* (1989).

3.4.6 Determination of phosphorus

Phosphorus in the digest was determined by ascorbic acid blue color method with the help of a spectrophotometer.

3.4.7 Determination of potassium

Potassium content in the digested plant sample was determined by flame photometer.

3.4.8 Determination of sulphur

The concentration of sulphur in the extract of grain and straw samples was determined by developing turbidity by adding acid seed solution (20 ppm S as K_2SO_4 in 6 N HCl) and $BaCl_2$ crystals. The intensity of turbidity was measured with the help of a spectrophotometer at the wavelength of 420 nm as described by Black (1965).

3.4.9 Determination of boron

The grain and straw samples were extracted by hot water and water-soluble boron was determined by Azomethine-H method. Exactly 1 mL extract of each of grain and straw samples was taken separately in polypropylene tubes followed by the addition of 1 mL of buffer solution and 1 mL Azomethine-H reagent. Absorbance was read at 420 nm following the instruction of Page *et al.,* (1989).

3.5 Statistical analysis

Data were statistically analyzed by analysis of variance (ANOVA) technique usuing the MSTAT Statistical Computer Package Programme in accordance with the principles of Randomized Completely Block Design (Steel and Torriee, 1960). Ducan's Multiple Range Test (DMRT) was used to compare variations among the treatments.

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

This chapter contains results of the experiment and the follow-up discussion. For convenience, the whole chapter has been divided into two sections:

i) Agronomic characteristics

ii) Nutrient contents

Indeed this was a study of the effects of different levels of sulphur and boron as well as their interaction effects on growth, yield and nutrient content of rice e.g. plant height, effective tillers hill^{-1}, non-effective tillers hill^{-1}, panicle length, number of filled grains panicle^{-1}, number of unfilled grains panicle^{-1} and 1000-grain weight while the chemical analyses of rice grain and straw include nitrogen, sulphur, boron, phosphorus, potassium as influenced by different levels of sulphur and boron. The results of the whole experiment are shown in Tables 4.1-4.7 and Figures 4.1-4.33 which have been discussed under the following sub-sections.

4.1 Effect of different levels of sulphur and boron on yield and yield attributes of BRRI dhan 30

4.1.1 Plant height

The plant height was not significantly affected by the application of sulphur (Appendix II). However, the tallest plant (116.96 cm) was achieved when sulphur was applied at the rate of 12 kg S ha^{-1}(S_2) and was statistically similar to S_1 and S_3 treatments and the shortest plant (114.3 cm) grew from S_0 treatment (Table 4.1 and Figure 4.1).

The plant height of the experimental crop was significantly ($p<0.05$) affected by the application of boron (Appendix II). B_2 treatment produced the tallest (117.07 cm) plant but the control treatment produced the shortest (112.8 cm) plant (Table 4.2 and Figure 4.2). Treatments B_1 and B_3 although produced higher plant height than B_0 treatment but they were indifferent with B_2 treatment.

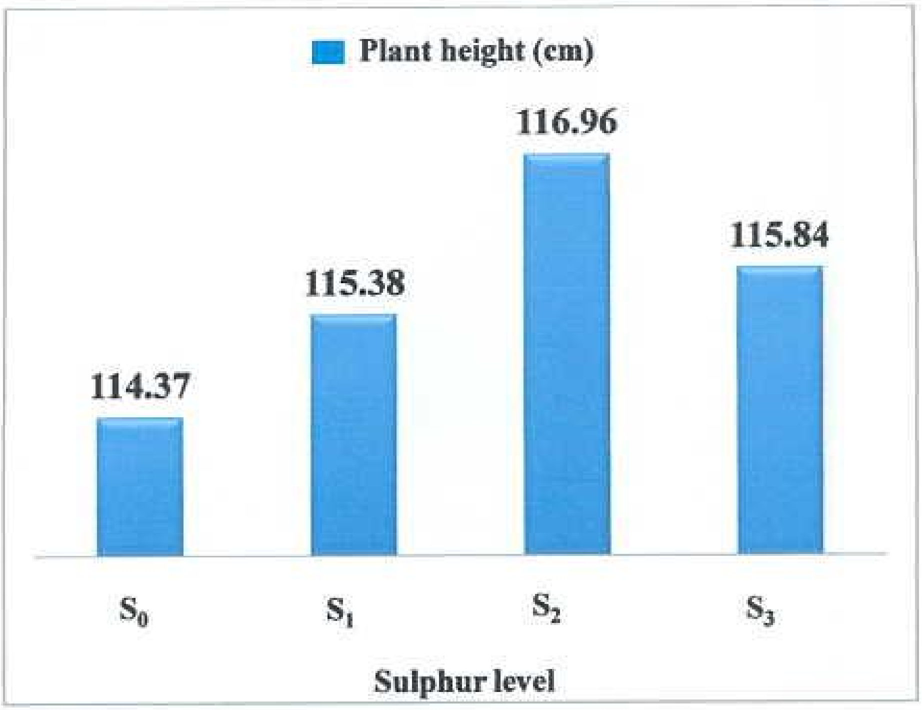


Figure 4.1 Effect of different levels of sulphur on plant height of BRRI dhan 30

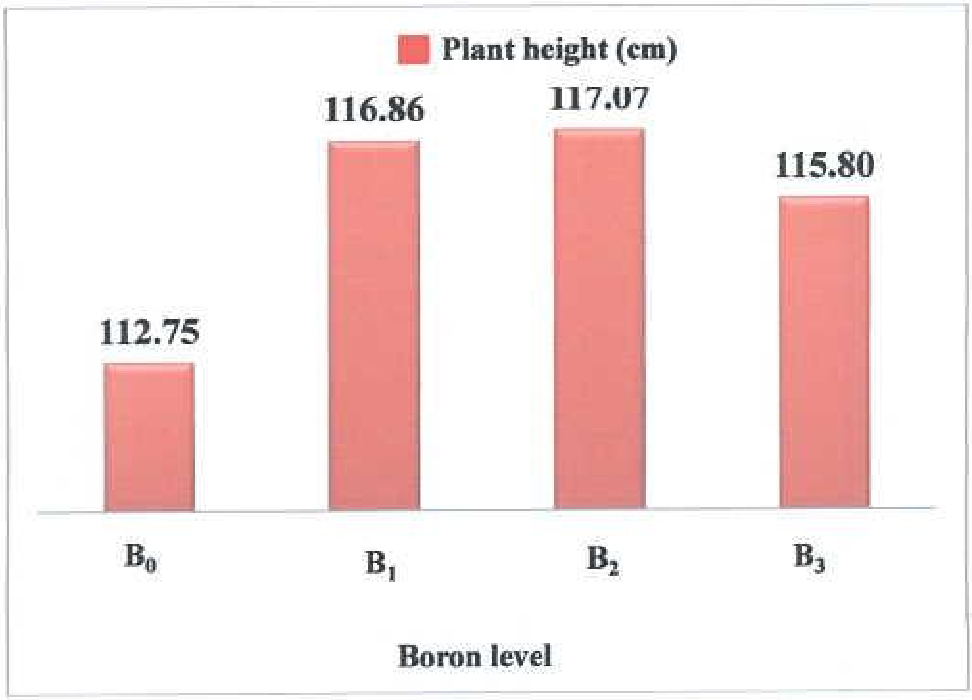


Figure 4.2 Effect of different levels of boron on plant height of BRRI dhan 30

The interaction effect of sulphur and boron on plant height was found to be non significant (Appendix II). However, the tallest plant (120.13 cm) was obtained with the treatment combination of S_2B_2 (120.13 cm) and the shortest (111.50 cm) was in control (Table 4.3).

4.1.2 Number of effective tillers hill^{-1}

The effect of sulphur on the number of effective tillers hill^{-1} was significant ($p<0.01$) (Appendix II). The data show that S_2 treatment produced the highest and S_0 treatment the lowest effective tillers hill^{-1}. The second highest number of effective tillers hill^{-1} was found from S_3, and was similar to S_1 treatments (Table 4.1 and Figure 4.3). It is revealed from the results that sulphur enhanced the number of effective tillers hill^{-1}. The results corroborate the findings of Islam *et al.,* (2009). Haque and Chowdhury (2004) also reported that number of effective tillers hill^{-1} of rice was increased by S application.

Variation in effective tillers hill^{-1} was found to be significant ($p<0.01$) due to boron application (Appendix II). Application of 1.0 kg B ha^{-1} (B_1) produced the highest effective tillers hill^{-1}. On the other hand, the lowest with control treatment. B_2 and B_3 treatments were statistically similar (Table 4.2 and Figure 4.4). From the above results, it is revealed that effective tillers hill^{-1} was influenced by boron.

Results presented in Table 4.3 shows that interaction effect of sulphur and boron in respect of effective tillers hill^{-1} was significant ($p<0.01$) (Appendix II). The highest number of effective tillers was found from the treatment combination of S_2B_1 (10.70 No.) treatment and the lowest (4.38 No.) from the control. The second highest was found with S_2B_2 treatment (Table 4.3). Such results indicate that interaction of sulphur and boron promoted the number of effective tillers hill^{-1}. Saliva and Castilla (2004) also reported that effective tillers hill^{-1} increased up to 5% by the application of sulphur and boron.

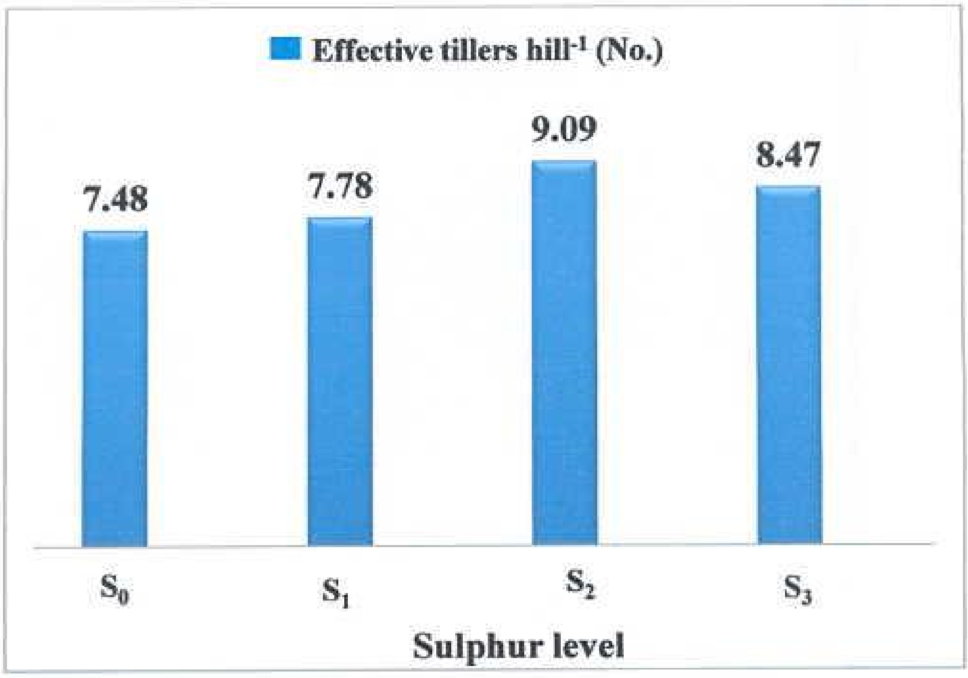


Figure 4.3 Effect of different levels of sulphur on effective tillers hill^{-1} (No.) of BRRI dhan 30

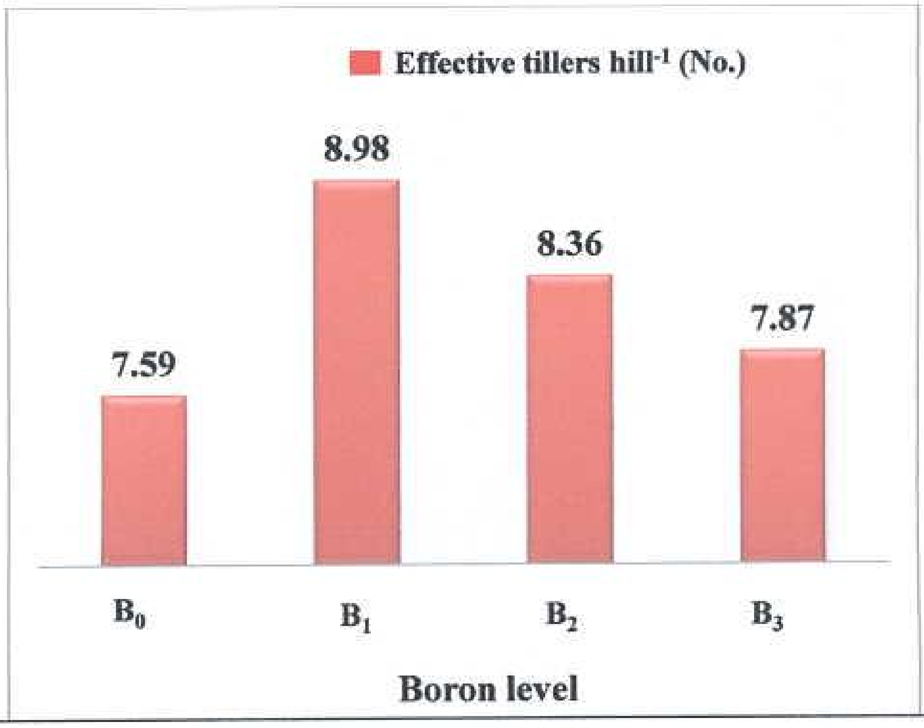


Figure 4.4 Effect of different levels of boron on effective tillers hill^{-1} (No.) of BRRI dhan 30

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

Sulphur brought about significant ($p<0.01$) variation in regard to non-effective tillers hill^{-1} (Appendix II). The highest (3.37) and lowest (2.84) number of non-effective tillers were found from control and S_2 treatments respectively. All other treatments were statistically identical except control (Table 4.1 and Figure 4.5)

Different levels of boron had a significant ($p<0.01$) effect on non-effective tillers hill^{-1} (Appendix II). Table 4.2 shows that control treatment produced the highest number (3.25) and B_3 (2.82) the lowest number of non-effective tillers hill^{-1}. B_1 and B_2 treatments were identical (Table 4.2 and Figure 4.6).

There was no significant variation between sulphur and boron interaction in relation to non-effective tillers hill^{-1} (Appendix II). Highest number of non-effective tillers (3.48) was found in control while lowest number (2.56) was found in S_2B_3 treatment (Table 4.3). It is apparent from the results that the joint application of sulphur and boron decreased non-effective tillers.

4.1.4 Panicle length

Panicle length varied significantly at 1% level of probability due to application of sulphur (Appendix II). S_2 treatment produced the highest panicle length (25.64 cm) and lowest (24.51 cm) was obtained from control (Figure 4.7). S_1, S_2 and S_3 treatments were statistically similar. The present study indicates that panicle length increased due to increasing levels of sulphur up to S_2 level and there after it decreased (Table 4.1).

There were numerical variations due to different boron levels regarding panicle length and they were statistically significant (Appendix II). However, highest (25.73 cm) and lowest (24.77 cm) panicle length were found from B_1 and B_0 treatments respectively. B_1, B_2, and B_3 treatments were statistically similar (Table 4.2 and Figure 4.8).

The treatment combinations of sulphur and boron was significant on panicle length. However, the panicle length varied from 25.15 cm to 26.02 cm due to S_0B_0 and S_2B_1 treatments respectively (Table 4.3).

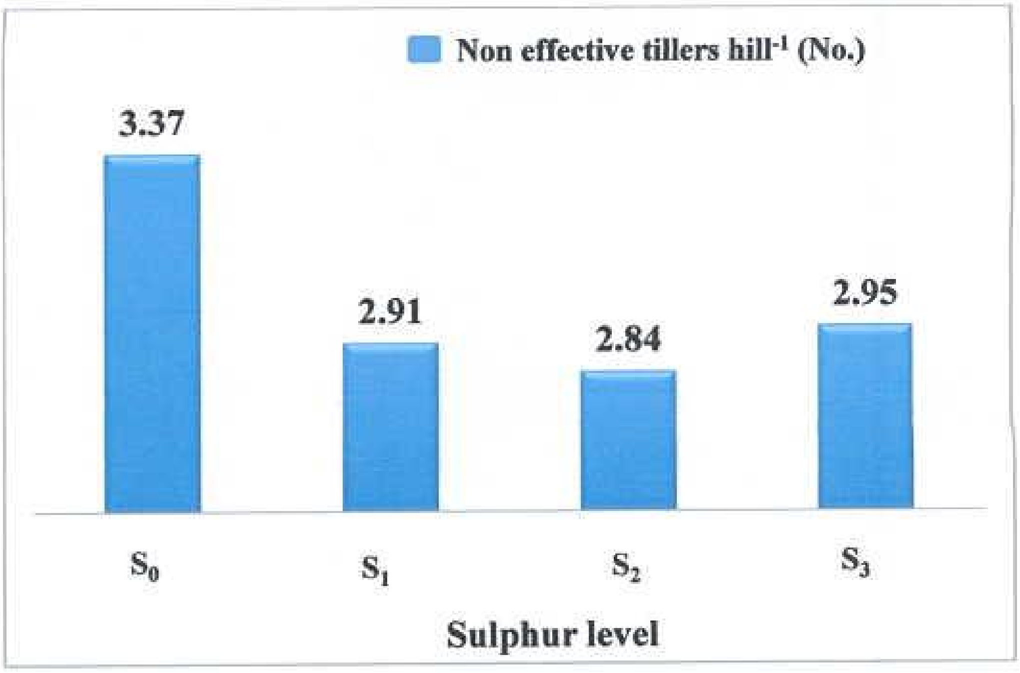


Figure 4.5 Effect of different levels of sulphur on non effective tillers hill^{-1} (No.) of BRRI dhan 30

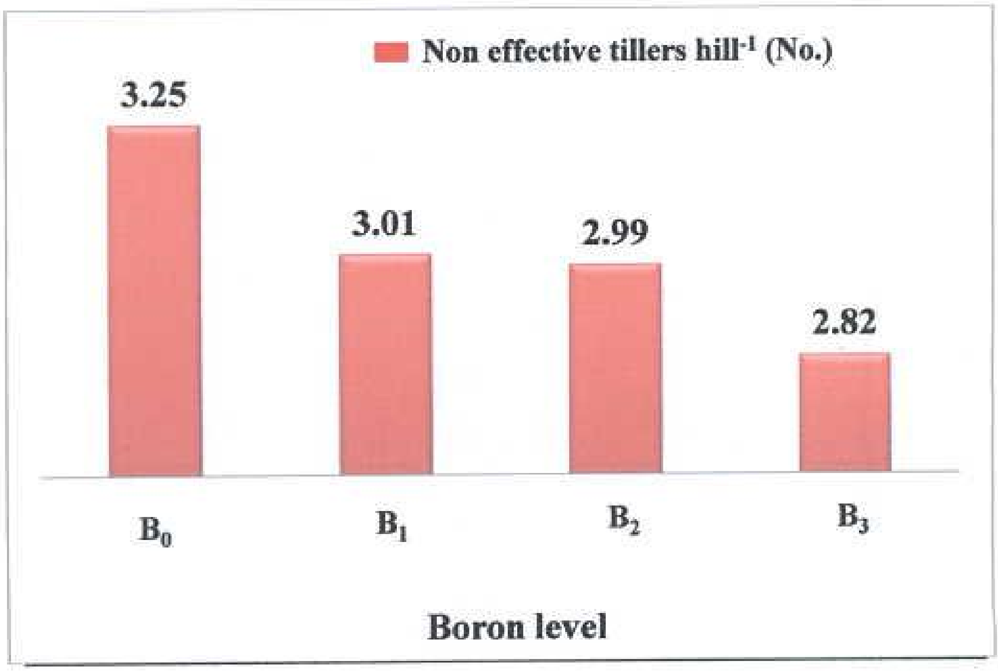


Figure 4.6 Effect of different levels of boron on non effective tillers hill^{-1} (No.) of BRRI dhan 30

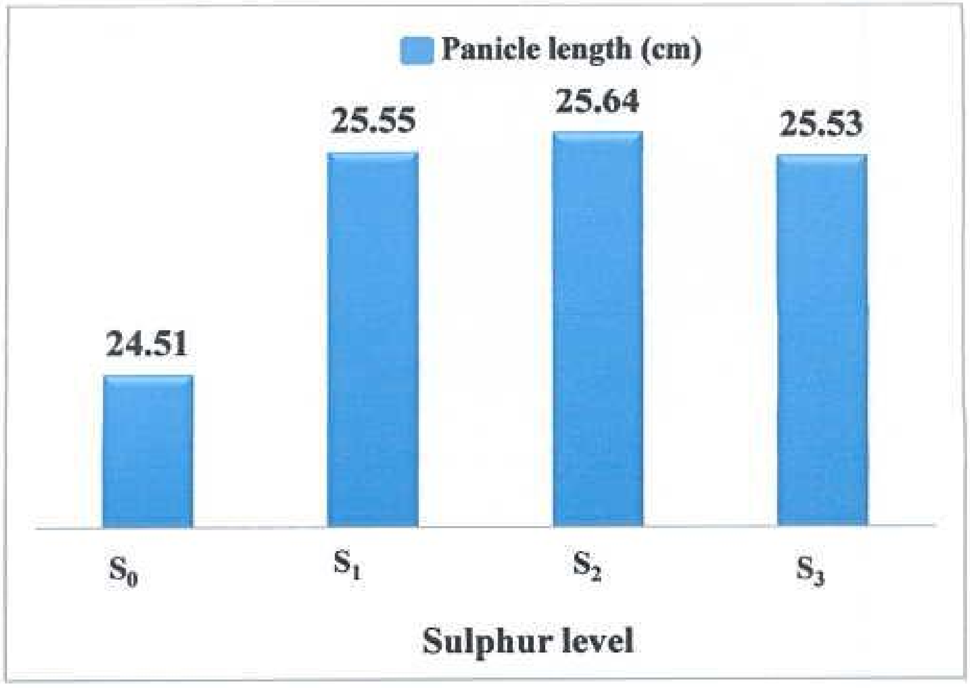


Figure 4.7 Effect of different levels of sulphur on panicle length (cm) of BRRI dhan 30

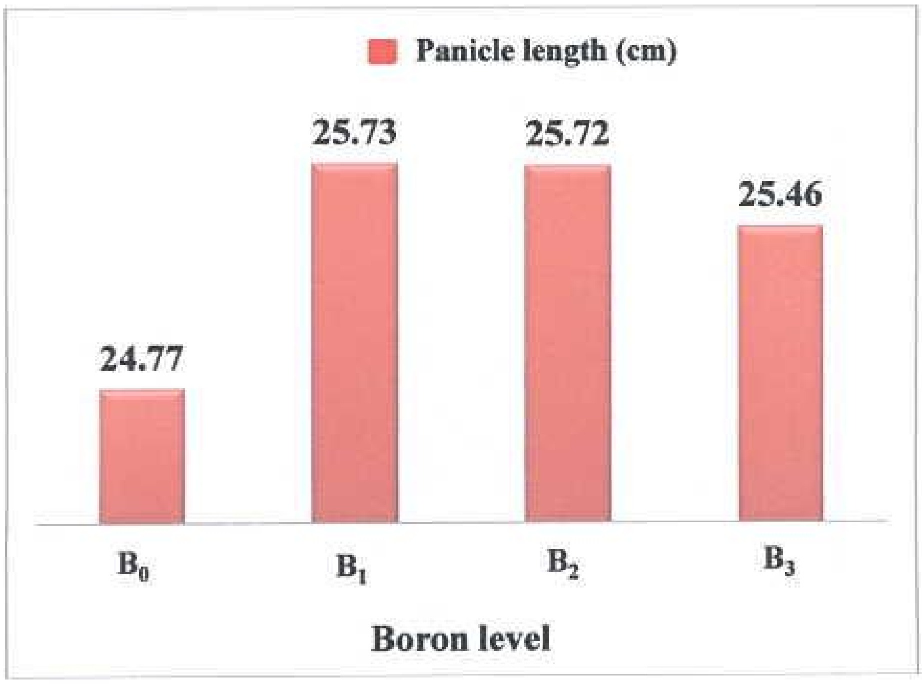


Figure 4.8 Effect of different levels of boron on panicle length (cm) of BRRI dhan 30

4.1.5 Number of filled grains panicle^{-1}

Appendix II shows that the number of filled grains panicle^{-1} significantly ($p<0.01$) varied due to application of sulphur. The highest number of filled grains (102.42) was found when the crop was fertilized with 12 kg S ha^{-1} (S_2 treatment) and the lowest (83.81) was in control. S_1 and S_3 treatments were statistically similar (Table 4.1). Although the increase in number of filled grain continued to S_2 treatment, it again decreased at S_3 level (Figure 4.9).

Application of boron increased the production of filled grains per panicle. This increase was statistically significant ($p<0.05$) (Appendix II). The highest number of filled grains panicle^{-1} was found from B_1 treatment and lowest from control. B_2 and B_3 treatments produced significantly higher number of filled grains than control but were lower than B_1 treatment (Table 4.2 and Figure 4.10).

Interaction effect of sulphur and boron failed to show any significant variation in the number of filled grains panicle^{-1}. However, the treatment combination S_2B_1 produced the highest number (104.60) of filled grains panicle^{-1} and in S_0B_0 treatment gave the lowest (Table 4.3).

4.1.6 Number of unfilled grains panicle^{-1}

There was a significant ($p<0.01$) effect of sulphur on unfilled grains panicle^{-1} (Appendix II). The highest unfilled grains panicle^{-1} was found with S_0 and the lowest from S_2 treatment (Table 4.1). It is evident from the results that application of sulphur decreased number of unfilled grains (Figure 4.11).

The effect of different boron levels was found to be non-significant on the production of unfilled grains panicle^{-1} (Appendix II). Comparatively higher unfilled grain was found from B_0 treatment and lower from B_1, B_2 and B_3 treatments (Table 4.2 and Figure 4.12).

Interaction effect of sulphur and boron was found to be significant ($p<0.05$) in relation to unfilled grain panicle^{-1} (Appendix II). Application of sulphur and boron together decreased the number of unfilled grains panicle^{-1}. The highest number of unfilled grains panicle^{-1} was recorded from S_1B_0 treatment and it was lowest in treatment S_2B_2 (Table 4.3).

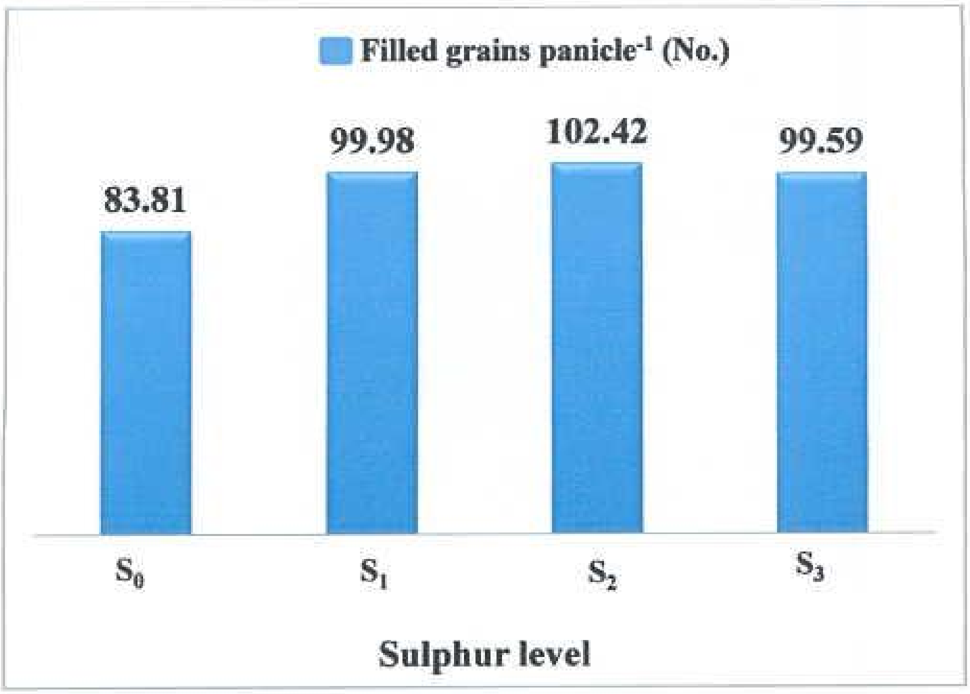


Figure 4.9 Effect of different levels of sulphur on filled grains panicle^{-1} (No.) of BRRI dhan 30

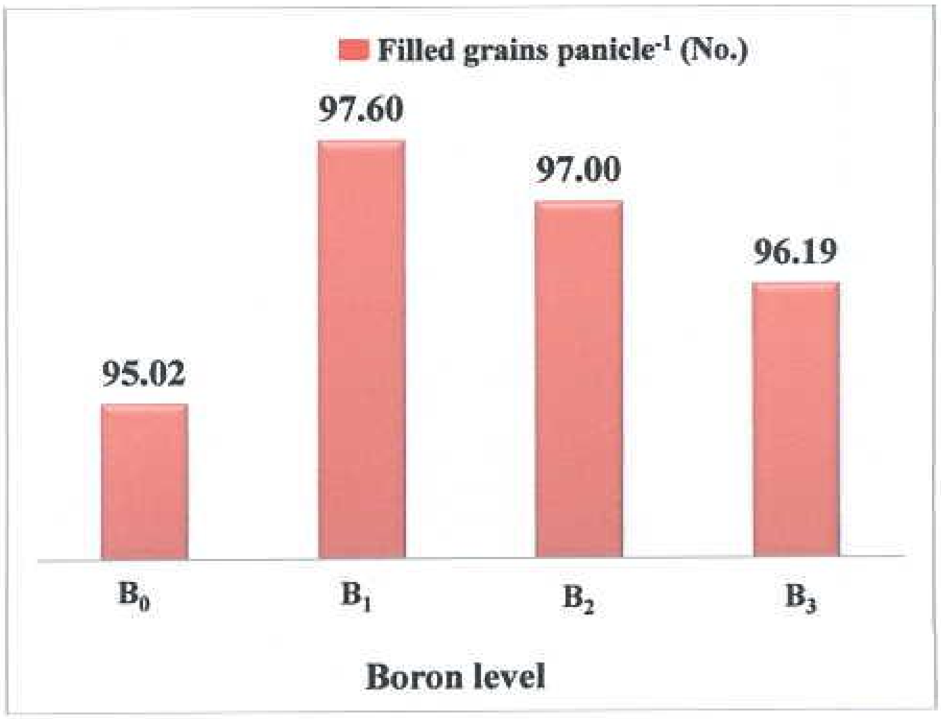


Figure 4.10 Effect of different levels of boron on filled grains panicle^{-1} (No.) of BRRI dhan 30

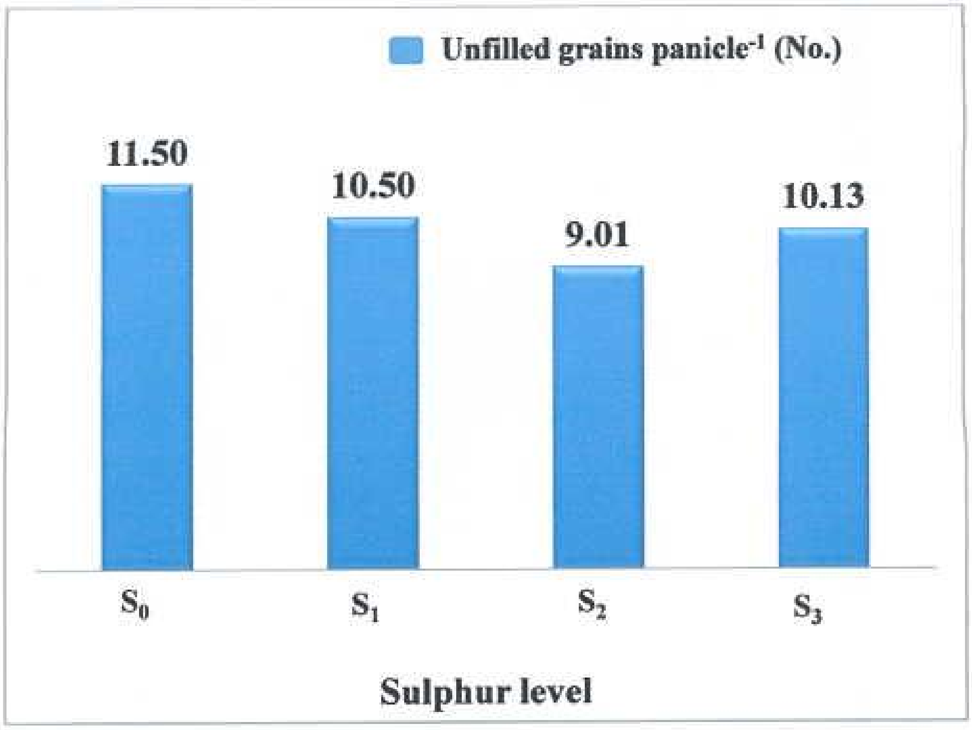


Figure 4.11 Effect of different levels of sulphur on unfilled grains panicle^{-1} (No.) of BRRI dhan 30

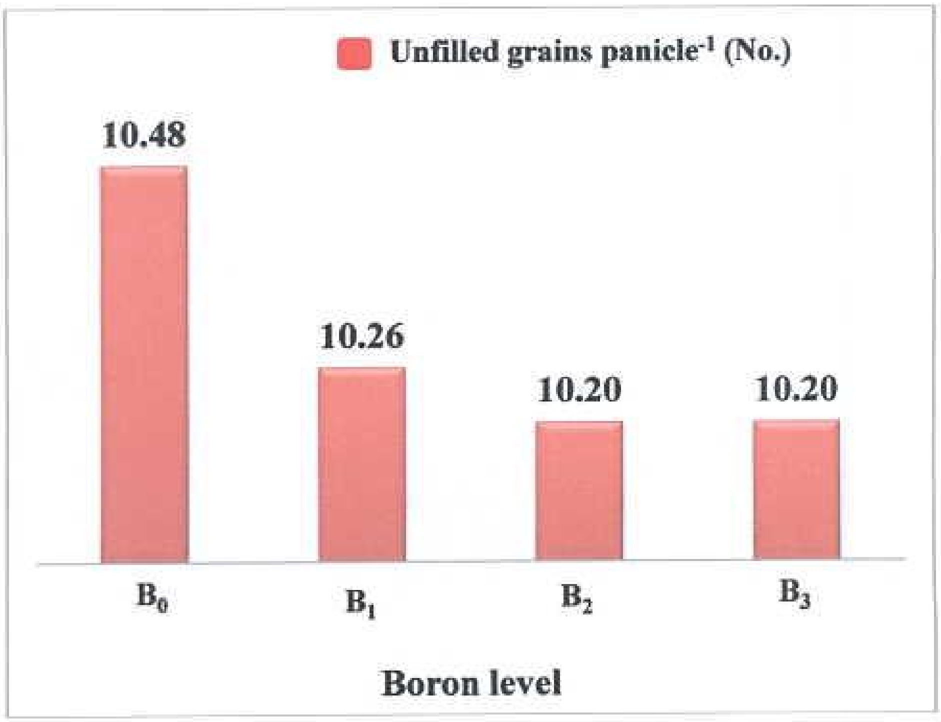


Figure 4.12 Effect of different levels of boron on unfilled grains panicle^{-1} (No.) of BRRI dhan 30

4.1.7 Weight of 1000-grain

1000-grain weight of BRRI dhan 30 varied significantly ($p<0.01$) by the application of sulphur (Appendix II). The heaviest grain weight (23.31 g) was achieved when sulphur was applied at the rate of 12.00 kg ha^{-1} (S_1 treatment), and was statistically similar to those given by S_2 (23.02 g) and S_3 (22.74 g) treatments (Figure 4.13). Yet there was a decreasing trend in 1000-grain weight of BRRI dhan 30 with the increase in dose of sulphur after 12.00 kg ha^{-1}. The S_0 treatment produced the lightest 1000-grain weight (21.61 g) (Table 4.1).

Appendix II shows that there was no significant variation in weight of 1000 grains due to application of boron. However, the maximum 1000-grain weight (23.01 g) was attained in B_2 treatment and the minimum (22.13 g) in control (Table 4.2). 1000-grain weight decreased with the increase in dose of boron beyond 1.50 kg ha^{-1} (Figure 4.14).

There was no significant effect in 1000-grain weight due to sulphur and boron interaction (Appendix II). However, the heaviest (23.98 g) and the lightest (21.28 g) grain weights were found from S_1B_1 and control treatments respectively (Table 4.3). The interaction effect of S and B also testify the phenomenon stated above that S and B at higher levels reduced the 1000-grain weight.

4.1.8 Grain yield

Grain yield was significantly ($p<0.01$) affected by application of sulphur (Appendix II). The highest (4.89 t ha^{-1}) and the lowest (4.41 t ha^{-1}) grain yields were found when the crop received 12 kg S ha^{-1} (S_2 treatment) and no sulphur (S_0) respectively (Table 4.1 and Fig. 4.15). Further it was observed that grain yield increased up to S_2 (12 kg S ha^{-1}) and thereafter it declined, but it was still superior to control. The pattern of grain yield was similar to that of panicle length. The result obtained in grain yield is in accordance with the findings of Jahiruddin and Islam (2009).

Appendix II shows that the application of boron had a significant variation at 1% level of probability regarding grain yield of rice. The highest grain yield (4.99 t ha^{-1}) was found from B_1 treatment which was statistically different from B_2 (4.69 t ha^{-1}) and B_3 (4.64 t ha^{-1}) treatments but the control treatment (B_0) produced the lowest (4.22 tha^{-1}) grain yield

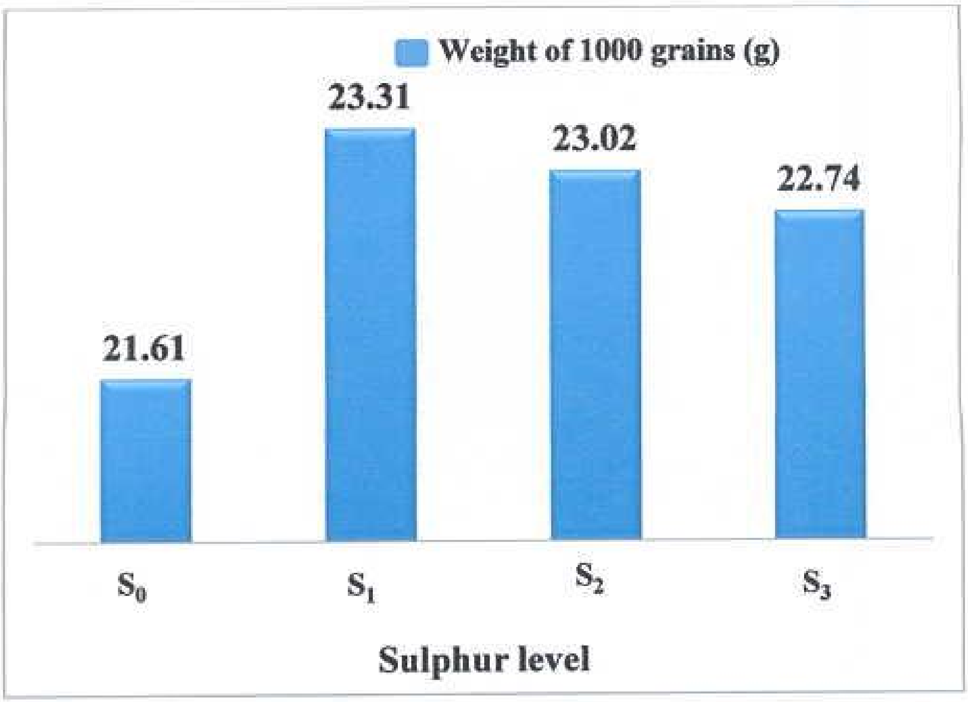


Figure 4.13 Effect of different levels of sulphur on weight of 1000 grains (g) of BRRI dhan 30

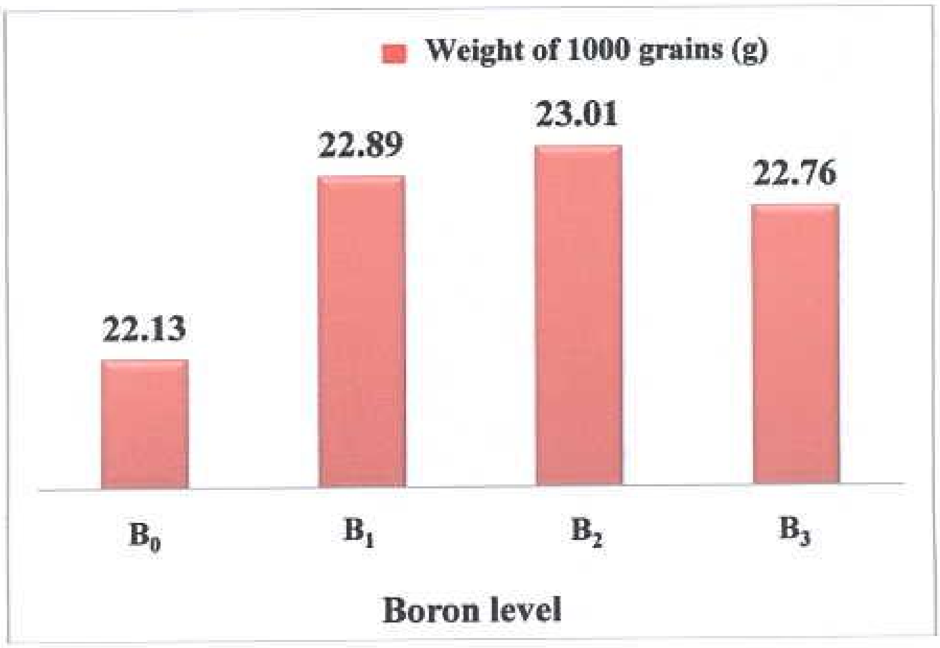


Figure 4.14 Effect of different levels of boron on weight of 1000 grains (g) of BRRI dhan 30

(Table 4.2 and Fig. 4.16). The results further show that the grain yield declined with increase in levels of boron more than 1 kg B ha^{-1}. Sharif *et al.*, (2006) reported that grain yield increased due to boron application.

Combine application of sulphur and boron had a significant ($p<0.01$) variation in relation to grain yield (Appendix II). The highest and the lowest grain yields were found from S_2B_1 (5.17 tha^{-1}) treatment and control S_0B_0 (3.94 t ha^{-1}) respectively (Table 4.3). The interaction effect clearly show that when levels of S was higher than 12 kg S ha^{-1} the yield of rice drastically reduced and this reduction in yield became more prominent when levels of S exceeded 12 kg S ha^{-1}.

4.1.9 Straw yield

Sulphur showed a significant ($p<0.01$) variation in straw yield (Appendix II). The highest straw yield (6.74 t ha^{-1}) was found in S_3 treatment and the lowest (6.20 t ha^{-1}) from control S_0 treatment. Yield of straw in S_0, S_1 and S_2 treatments were statistically similar (Table 4.1 and Figure 4.15). The findings of this character agree with the result obtained by Shah *et al.*, (2009).

Boron also showed significant ($p<0.01$) effect on straw yield (Appendix I). The highest straw yield (7.08 t ha^{-1}) was found from B_1 treatment and the lowest (6.00 t ha^{-1}) from B_0 treatment. The second highest straw yield (6.49 t ha^{-1}) was obtained from B_3 treatment but the pattern of increase or decrease was not regular (Table 4.2 and Figure 4.16). Rahmatullah *et al.*,(2006) reported that straw yield was increased by boron application.

Results presented in Table 4.3 shows that interaction effects of sulphur and boron were significantly ($p<0.01$) influenced on the straw yield (Appendix II). The highest straw yield (7.97 t ha^{-1}) was found in S_2B_1 treatment and the lowest (5.58 t ha^{-1}) from S_0B_0 treatment (Table 4.3). It is apparent from the above results that combined application of sulphur and boron along with N, P and K increased the straw yield. But at highest levels of both S and B, the yield declined considerably.

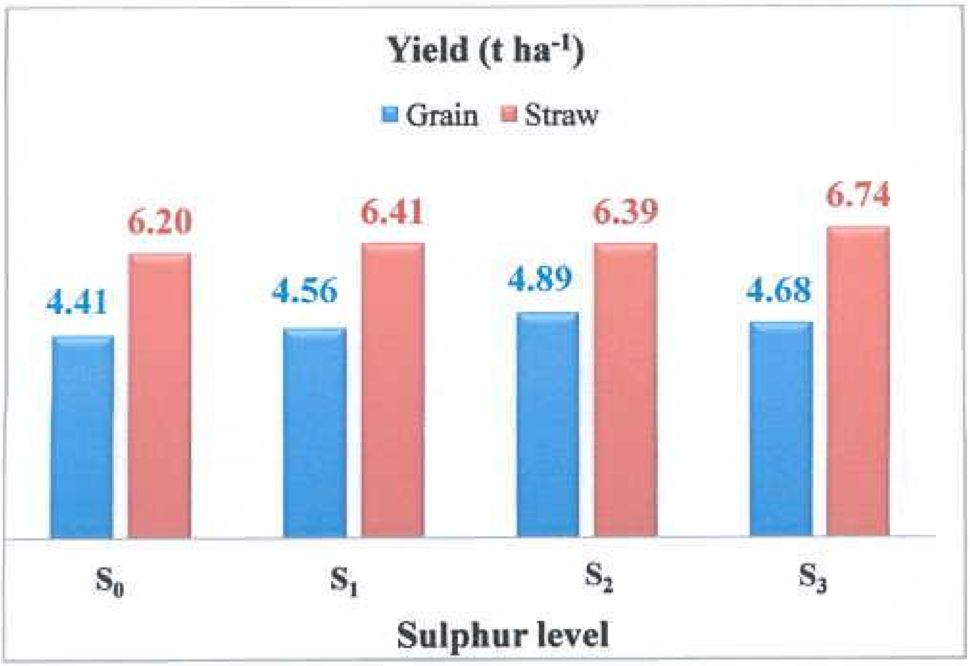


Figure 4.15 Effect of different levels of sulphur on rice grain and straw yields of BRRI dhan 30

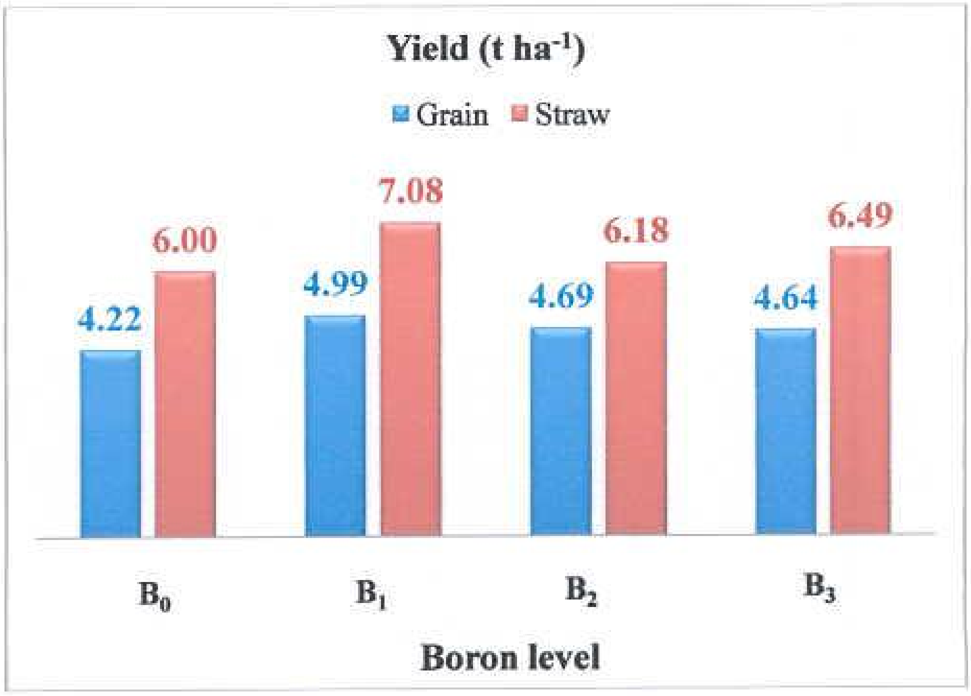


Figure 4.16 Effect of different levels of boron on rice grain and straw yields of BRRI dhan 30

Table 4.1 Effects of different levels of sulphur on yield and yield attributes of rice (BRRI dhan 30)

Treatment	Plant height (cm)	Effective Tillers hill^{-1} (No.)	Non-Effective Tillers hill^{-1} (No.)	Panicle length (cm)	Filled Grains Panicle^{-1} (No.)	Unfilled Grains Panicle^{-1} (No.)	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
S_0	**114.37 b**	**7.48 c**	**3.37 a**	**24.51 b**	**83.81 c**	**11.50 a**	**21.61 b**	**4.41 c**	**6.20 b**
S_1	115.38 a	7.78 c	2.91 b	25.55 a	99.98 b	10.50 b	**23.31 a**	4.56 bc	6.41 b
S_2	**116.96 a**	**9.09 a**	**2.84 b**	**25.64 a**	**102.42 a**	**9.01 c**	23.02 a	**4.89 a**	6.39 b
S_3	115.84 a	8.47 b	2.95 b	25.53 a	99.59 b	10.13 b	22.74 a	4.68 b	**6.74 a**
CV (%)	2.15	9.97	6.13	3.38	2.25	5.64	3.60	4.23	4.24

Values with common letter (s) in a column do not differ significantly

CV- Coefficient of variance

S_0 : 0 kg S ha^{-1}

S_1: 8 kg S ha^{-1}

S_2: 12 kg S ha^{-1}

S_3: 16 kg S ha^{-1}

Table 4.2 Effects of different levels of boron on yield and yield attributes of rice (BRRI dhan 30)

Treatment	Plant height (cm)	Effective Tillers hill^{-1} (No.)	Non-Effective Tillers hill^{-1} (No.)	Panicle length (cm)	Filled Grains Panicle^{-1} (No.)	Unfilled Grains Panicle^{-1} (No.)	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
B_0	**112.75 b**	**7.59 b**	**3.25 a**	**24.77 b**	**95.02 b**	**10.48 a**	**22.13 a**	**4.22 c**	**6.00 c**
B_1	116.86 a	**8.98 a**	3.01 b	**25.73 a**	**97.60 a**	10.26 a	22.89 a	**4.99 a**	**7.08 a**
B_2	**117.07 a**	8.36 a	2.99 b	25.72 a	97.00 ab	**10.20 a**	**23.01 a**	4.69 b	6.18 c
B_3	115.8 a	7.87 b	**2.82 c**	25.46 a	96.19 ab	**10.20 a**	22.76 a	4.64 b	6.49 b
CV (%)	2.15	9.97	6.13	3.38	2.25	5.64	3.60	4.23	4.24

Values with common letter (s) in a column do not differ significantly

CV- Coefficient of variance

B_0 : 0 kg B ha^{-1} B_2: 1.5 kg B ha^{-1}

B_1: 1 kg B ha^{-1} B_3: 2 kg B ha^{-1}

Table 4.3 Interaction effects of different levels of sulphur and boron on yield and yield attributes of rice (BRRI dhan 30)

Treatment	Plant height (cm)	Effective Tillers hill^{-1} (No.)	Non-Effective Tillers hill^{-1} (No.)	Panicle length (cm)	Filled Grains Panicle^{-1} (No.)	Unfilled Grains Panicle^{-1} (No.)	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
S_0B_0	**111.50 c**	**4.38 d**	**3.48 a**	**25.15 a**	**82.19 c**	11.40 ab	**21.28 d**	**3.94 g**	**5.58 g**
S_0B_1	117.13 a	7.77 bc	3.46 a	25.50 a	87.33 bc	9.66 def	22.20 c	4.77 bcd	6.67 bcd
S_0B_2	114.50 b	8.567 bc	3.30 a	25.87 a	83.33 c	10.36 bcd	21.59 cd	4.45 def	6.22 def
S_0B_3	114.36 b	8.733 bc	3.26 a	21.53 b	82.42 c	10.60 bcd	21.38 d	4.48 def	6.04 efg
S_1B_0	112.03 c	8.200 bc	3.16 a	25.38 a	99.26 b	**12.33 a**	22.72 bc	4.26 efg	5.96 efg
S_1B_1	115.33 ab	7.267 bc	2.83 ab	25.15 a	99.46 b	11.03 bc	**23.98 a**	4.91 abc	6.79 bc
S_1B_2	117.05 a	7.733 bc	3.03 ab	26.05 a	100.93 ab	11.40 ab	23.20 ab	4.87 abc	6.81 bc
S_1B_3	117.13 a	7.933 bc	2.63 c	25.64 a	100.30 ab	11.26 bc	23.37 ab	4.20 efg	6.08 efg
S_2B_0	111.86 c	8.367 bc	3.26 a	26.10 a	102.80 a	9.16 ef	22.67 bc	4.57 cde	6.39 cde
S_2B_1	118.83 a	**10.70 a**	**2.56 c**	**26.02 a**	**104.60 a**	8.90 f	23.05 b	**5.17 a**	**7.97 a**
S_2B_2	**120.13 a**	8.967 b	2.66 c	25.56 a	102.56 ab	**8.84 f**	23.52 ab	5.08 ab	5.90 efg
S_2B_3	117.26 a	8.567 bc	2.90 ab	24.88 a	99.70 b	9.15 ef	22.87 bc	4.81 abcd	6.73 bc
S_3B_0	115.63 ab	8.767 bc	3.10 a	25.23 a	98.03 b	10.16 cde	23.10 b	4.12 fg	5.76 fg
S_3B_1	116.33 ab	8.300 bc	2.86 ab	25.56 a	100.80 ab	10.36 bcd	22.77 bc	5.11 ab	6.89 bc
S_3B_2	116.60 ab	8.400 bc	3.00 ab	25.46 a	101.26 a	10.20 cde	22.41 c	4.37 ef	6.11 ef
S_3B_3	114.80 b	8.167 bc	2.86 ab	25.89 a	98.36 b	9.80 def	22.69 bc	5.09 ab	7.14 b
CV (%)	2.15	9.97	6.13	3.38	2.25	5.64	3.60	4.23	4.24

In a column values with common letter (s) or without letter do not differ significantly whereas; values with differs letter (s) differ significantly
CV- Coefficient of variance
S_0 : 0 kg S ha^{-1}, S_1 : 8 kg S ha^{-1}, S_2 : 12 kg S ha^{-1}, S_3 : 16 kg S ha^{-1}
B_0 : 0 kg B ha^{-1}, B_1 : 1 kg B ha^{-1} B_2 : 1.5 kg B ha^{-1} B_3 : 2 kg B ha^{-1}

4.2 Effect of different levels of sulphur and boron on nutrient content of rice cv. BRRI dhan 30

4.2.1 Nitrogen content in grain

The single effect of sulphur on nitrogen content in grain was statistically significant (Table 4.4 and Figure 4.17). It was found that sulphur application increased the nitrogen content in grain. The highest N content (1.27%) was obtained in S_2 treatment. The lowest N content was found in control (1.14%) and was statistically identical to S_1 treatment.

The effect of boron on N content in grain was not significant (Table 4.5 and Figure 4.18). The content of N in rice grain was however highest at B_1 treatment and in subsequent treatments it gradually decreased with increase in level of B. It was lowest (1.17%) in control treatment.

The data revealed that the interaction effect of sulphur and boron was not significant (Table 4.6). The combined application of sulphur and boron increased N content in an irregular pattern. The highest N content (1.30%) was found in S_2B_1 and the lowest (1.12%) was in control.

4.2.2 Nitrogen content in straw

In case of rice straw the single effect of sulphur varied significantly on N content. It was observed that the N content in straw increased gradually up to S_2 treatment which was the highest (0.66%) and then it decreased. The lowest N content (0.50%) was found in control (Table 4.4 and Figure 4.17).

The effect of different levels of boron on N content in straw was statistically significant but the difference was very little. The highest N content (0.60%) in rice straw was observed in B_1 treatment and the lowest N content (0.56%) was found in control (Table 4.5 and Figure 4.18).

The interaction effect of sulphur and boron on N content in rice straw significant at 5% level of probability due to the treatment combinations. The highest N content (0.68%) in rice straw was found in S_2B_1 treatment and the lowest (0.48%) was found in control treatment (Table 4.6). However, it could be found from the table that when in combination S was used up to the level of 12 kg ha^{-1} the effect of B was prominent but at highest level of sulphur application it declined.

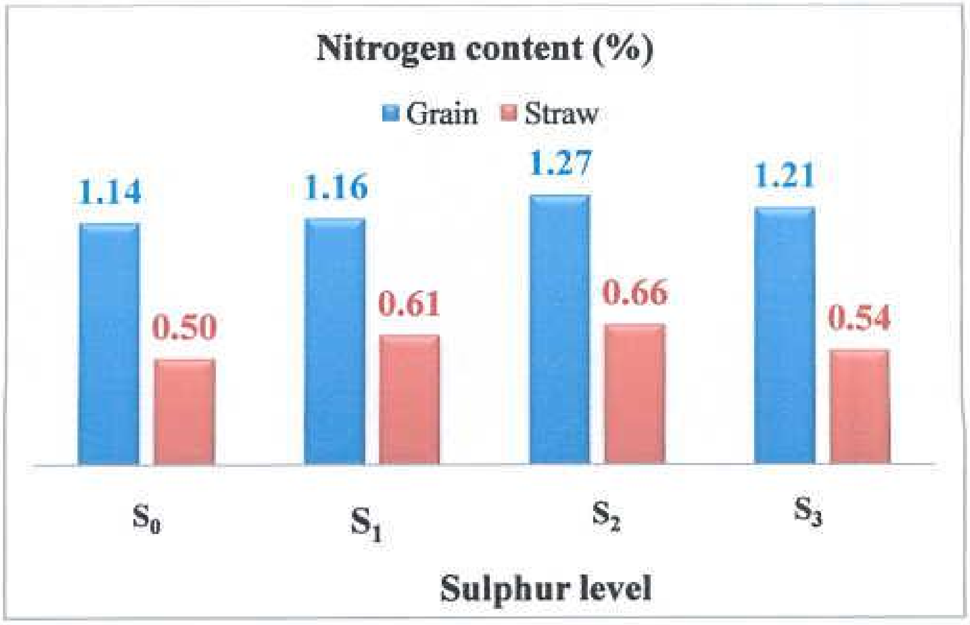


Figure 4.17 Effect of different levels of sulphur on nitrogen content of grain and straw of BRRI dhan 30

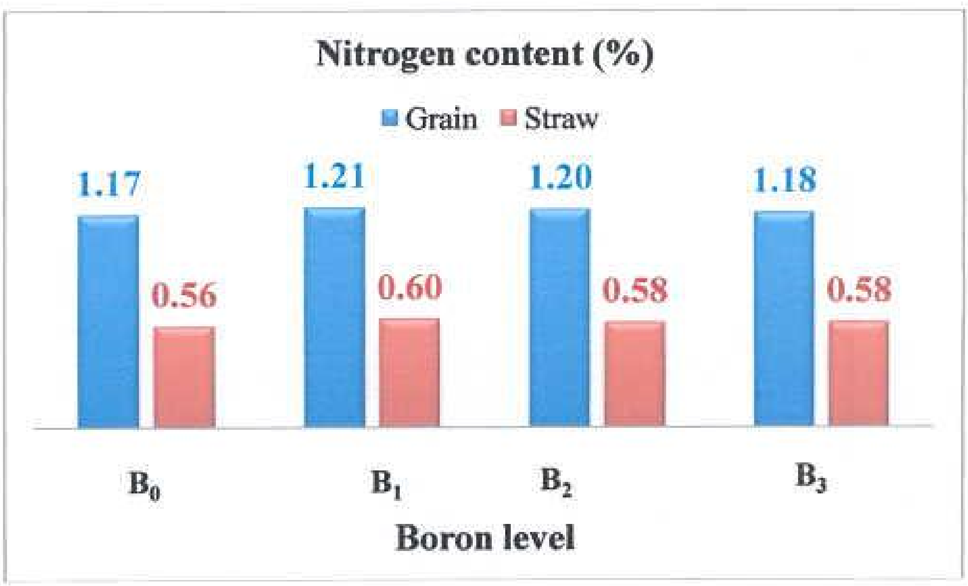


Figure 4.18 Effect of different levels of boron on nitrogen content of grain and straw of BRRI dhan 30

Table 4.4 Effects of different levels of sulphur on nitrogen, phosphorus, potassium, sulphur and boron content of rice grain and straw of rice (BRRI dhan 30)

Treatment	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Sulphur (%)		Boron ($\mu g\ g^{-1}$)	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
S_0	**1.14 c**	**0.50 d**	**0.25 d**	**0.14 b**	**0.62 b**	**1.48 d**	**0.135 c**	**0.116 b**	14.81 b	14.30 b
S_1	1.16 c	0.61 b	0.29 c	0.16 b	0.67 b	1.69 c	0.154 b	0.130 a	15.72 a	14.13 b
S_2	**1.27 a**	**0.66 a**	**0.31 a**	**0.18 a**	0.71 a	**1.78 a**	**0.170 a**	**0.136 a**	**15.98 a**	**14.95 a**
S_3	1.21 b	0.54 c	0.30 b	0.18 a	**0.73 a**	**1.78 a**	0.158 b	0.129 a	**13.31 c**	**13.50 c**
CV (%)	3.58	3.42	6.26	11.00	6.64	3.26	8.23	8.39	3.20	2.49

Values with common letter (s) in a column do not differ significantly

CV- Coefficient of variance

S_0 : 0 kg S ha^{-1} S_2: 12 kg S ha^{-1}

S_1: 8 kg S ha^{-1} S_3: 16 kg S ha^{-1}

Table 4.5 Effects of different levels of boron on nitrogen, phosphorus, potassium, sulphur and boron content of rice grain and straw of rice (BRRI dhan 30)

Treatment	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Sulphur (%)		Boron (µg g^{-1})	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
B_0	1.17 a	**0.56 c**	**0.26 a**	**0.154 d**	**0.67 b**	**1.495 d**	**0.140 c**	0.124 b	**10.79 c**	**10.82 c**
B_1	**1.21 a**	**0.60 a**	0.29 a	**0.177 a**	**0.71 a**	**1.785 a**	**0.174 a**	0.128 ab	**16.93 a**	**16.04 a**
B_2	1.20 a	0.58 b	**0.30 a**	0.170 b	0.69 b	1.727 b	0.156 b	**0.136 a**	15.39 b	14.04 b
B_3	1.18 a	0.58 b	**0.30 a**	0.169 b	0.68 b	1.725 b	0.146 c	**0.122 b**	16.72 a	15.98 a
CV (%)	3.58	3.42	6.26	11.00	6.64	3.26	8.23	8.39	3.20	2.49

Values with common letter (s) in a column do not differ significantly

CV- Coefficient of variance

B_0 : 0 kg B ha^{-1} B_2: 1.5 kg B ha^{-1}

B_1: 1 kg B ha^{-1} B_3: 2 kg B ha^{-1}

Table 4.6 Interaction effects of different levels of sulphur and boron on nitrogen, phosphorus, potassium, sulphur and boron content of rice grain and straw of rice (BRRI dhan 30)

Treatment	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Sulphur (%)		Boron (μg g^{-1})	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
S_0B_0	**1.12 cd**	**0.48 j**	**0.202 d**	**0.138 e**	**0.61 h**	**1.00 d**	**0.125 f**	**0.103 d**	**10.16 g**	**10.84 gh**
S_0B_1	1.13 cd	0.52 h	0.250 c	0.165 bcd	0.68 d	1.64 c	0.145 cd	0.119 c	14.33 d	13.89 ef
S_0B_2	1.17 c	0.51 hi	0.279 c	0.159 d	0.61 h	1.65 c	0.141 cd	0.127 bc	16.01bc	16.37 b
S_0B_3	1.13 cd	0.50 i	0.284 c	0.144 e	0.63 g	1.63 c	0.129 e	0.113 c	15.66 c	16.10 b
S_1B_0	1.14 cd	0.57 f	0.283 c	0.154 d	0.67 ef	1.64 c	0.137 e	0.125 bc	11.18 f	11.10 g
S_1B_1	1.18 c	0.65 bc	0.285 c	0.156 d	0.66 ef	1.72 bc	0.175 b	0.126 bc	17.99 a	14.46 de
S_1B_2	1.16 c	0.59 e	0.289 c	0.158 d	0.69 d	1.74 bc	0.162 bc	0.140 a	18.07 a	15.99 b
S_1B_3	1.15 c	0.63 d	0.293 bc	0.164 cd	0.66 ef	1.69 c	0.143 cd	0.126 bc	16.56 b	14.97 cd
S_2B_0	1.22 ab	0.64 cd	0.294 bc	0.155 d	0.68 d	1.65 c	0.155 cd	0.136 ab	11.15 f	11.01 g
S_2B_1	**1.30 a**	**0.68 a**	**0.327 a**	**0.198 a**	0.72 c	1.69 c	**0.189 a**	**0.141 a**	**18.76 a**	**17.93 a**
S_2B_2	1.28 a	0.66 b	0.315 ab	0.186 ab	0.74 b	1.83 ab	0.171 b	0.135 ab	18.28 a	16.49 b
S_2B_3	1.26 a	0.65 bc	0.316 ab	0.184 ab	0.72 c	1.75 bc	0.167 bc	0.133 b	17.94 a	14.36 de
S_3B_0	1.19 c	0.54 g	0.300 b	0.169 bcd	0.72 c	1.69 c	0.145 cd	0.133 b	10.68 fg	10.35 h
S_3B_1	1.23 ab	0.55 g	0.313 ab	0.190 a	0.71 c	1.90 a	0.188 a	0.128 bc	12.67 e	13.45 f
S_3B_2	1.21 ab	0.56 fg	0.307 abc	0.179 abc	**0.76 a**	**1.88 a**	0.152 c	0.139 a	15.36 c	15.31 c
S_3B_3	1.20 ab	0.52 h	0.309 abc	0.187 ab	0.74 b	1.83 ab	0.145 cd	0.114 c	14.51 d	14.90 cd
CV (%)	3.58	3.42	6.26	11.0	6.64	3.26	8.23	8.39	3.20	2.49

In a column values with common letter (s) or without letter do not differ significantly whereas; values with differs letter (s) differ significantly

CV- Coefficient of variance

S_0 : 0 kg S ha^{-1}
S_1: 8 kg S ha^{-1}
S_2 : 12 kg S ha^{-1}
S_3 : 16 kg S ha^{-1}

B_0: 0 kg B ha^{-1}
B_1: 1 kg B ha^{-1}
B_2 : 1.5 kg B ha^{-1}
B_3 : 2 kg B ha^{-1}

4.2.3 Phosphorus content in grain

The P concentration in rice cv. BRRI dhan 30 was influenced significantly by the application of sulphur (Tables 4.4). The p content in grain varied from 0.25 to 0.31 %. The maximum P content was recorded in the treatment S_2 (12 kg S ha^{-1}). The lowest P content was found in control (Figure 4.19).

The effect of different levels of boron on P content in grain was statistically significant (Table 4.5). The maximum P content (0.30%) was recorded in B_2 and B_3 treatments and the minimum (0.26%) was in control (Figure 4.20).

The interaction effect of sulphur and boron on P content in rice grain was significant. The P content due to the combination treatments of sulphur and boron ranged from 0.202% to 0.327%. The highest P content was observed in S_2B_1 treatment and the lowest was in S_0B_0 treatment (Table 4.6).

4.2.4 Phosphorus content in straw

In case of rice straw the single effect of sulphur varied significantly on P content. It was observed that the P content in straw increased gradually up to S_3 treatment which was the highest (0.18%) then it decreased. The lowest P content (0.14 %) was found in control (Tables 4.4 and Figure 4.19).

The effect of different levels of boron on P content in straw was statistically significant but the difference was very little. The highest P content (0.177%) in rice straw was observed in B_1 treatment and the lowest P content (0.154%) was found in control (Table 4.5 and Figure 4.20).

The interaction effect of sulphur and boron on P content in rice straw was significant at 5% level of probability due to the treatment combinations. The highest P content (0.198%) in rice straw was found in S_2B_1 treatment and the lowest (0.138%) was found in control treatment (Table 4.6).

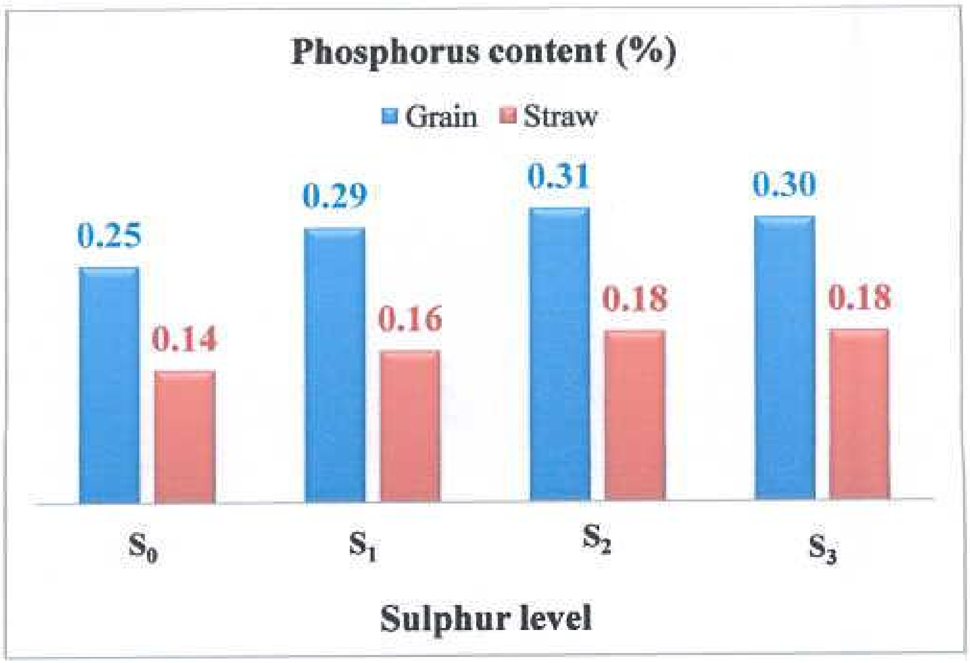


Figure 4.19 Effect of different levels of sulphur on phosphorus content of grain and straw of BRRI dhan 30

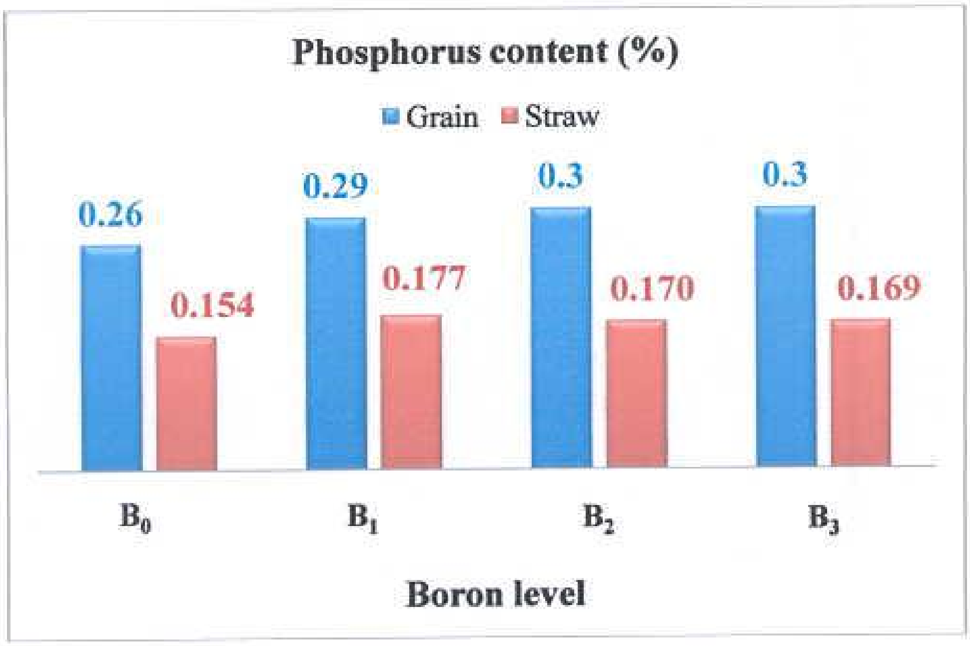


Figure 4.20 Effect of different levels of boron on phosphorus content of grain and straw of BRRI dhan 30

4.2.5 Potassium content in grain

The results on the K concentration in the grain of rice cv. BRRI dhan 30 have been presented in Table 4.4. The K content in rice grain was significantly influenced by the application of different sulphur levels. Application of sulphur increased K content in rice grain. The maximum K content (0.73 %) was recorded in S_3 treatment and second highest treatment was S_2 which was statistically similar. The lowest K content (0.62 %) was found in S_0 treatment (Figure 4.21).

The concentration of K in rice grain was statistically increased by the application of boron (Table 4.5). The highest K content (0.71%) was recorded in B_2 treatment and the lowest K content (0.67 %) was found in B_0 treatment (Figure 4.22).

The interaction effect of sulphur and boron on K content in rice grain was significant. The K content due to the combination treatments of sulphur and boron ranged from 0.61 % to 0.76%. The highest K content was observed in S_3B_2 treatment and the lowest was in S_0B_0 treatment (Table 4.6).

4.2.6 Potassium content in straw

In case of rice straw the single effect of sulphur varied significantly on K content. It was observed that the K content gradually increased up to S_2 and S_3 treatments which was the highest K content (1.78%) and the lowest K content (1.48 %) was found in S_0 treatment (Table 4.4 and Figure 4.21).

In the straw of rice cv. BRRI dhan 30, there was a significant variation among the K content as influenced by boron. The B_1 treatment produced the highest K content (1.785 %) in rice straw which was statistically significant. The lowest K content (1.495 %) was found in control (Table 4.5 and Figure 4.22).

The interaction effect of sulphur and boron on K content in rice straw significant at 5% level of probability due to the treatment combinations. The highest K content (1.88 %) in rice straw was found in S_3B_2 treatment and the lowest (1.00 %) was found in control treatment (Table 4.6).

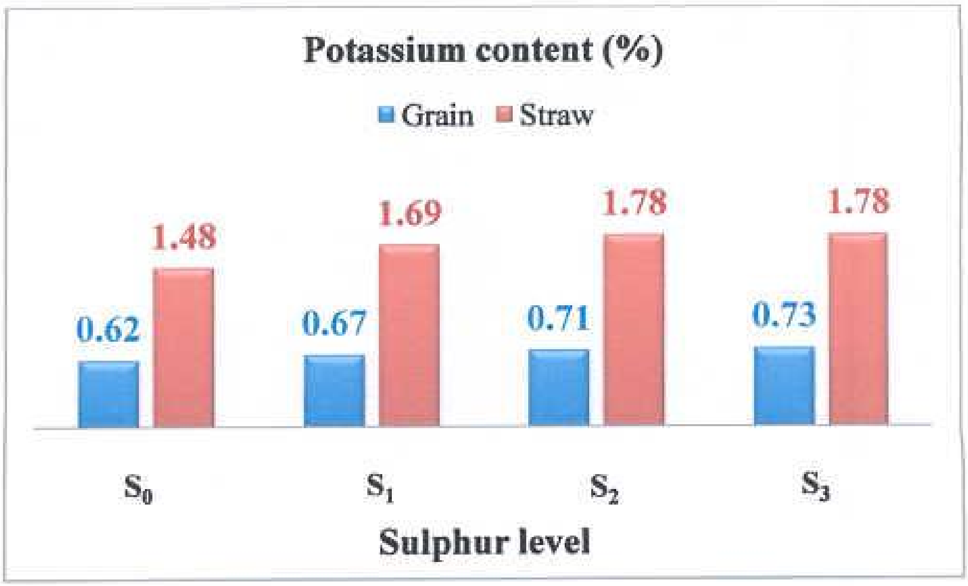


Figure 4.21 Effect of different levels of sulphur on potassium content of grain and straw of BRRI dhan 30

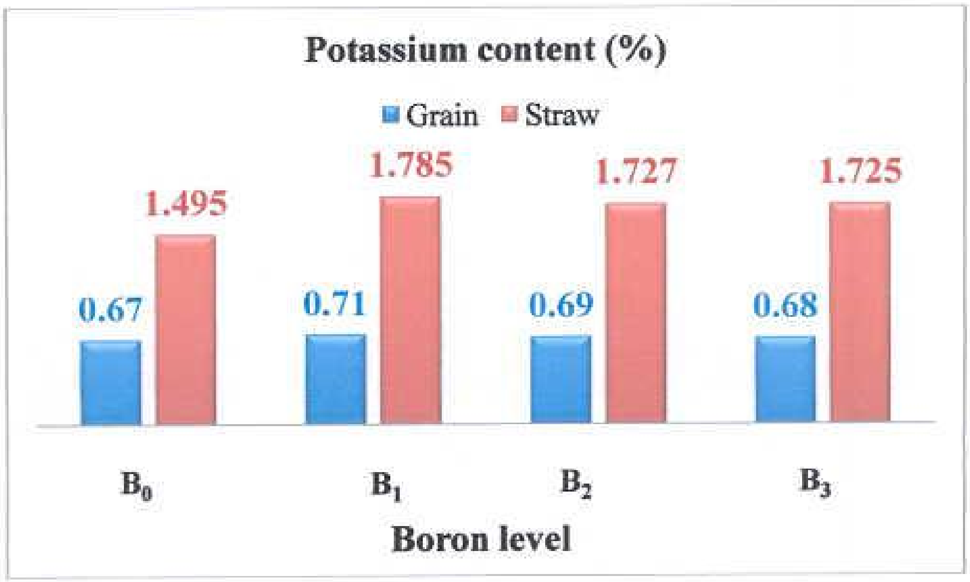


Figure 4.22 Effect of different levels of boron on potassium content of grain and Straw of BRRI dhan 30

4.2.7 Sulphur content in grain

The concentration of S in the grain of BRRI dhan 30 was influenced significantly by the different sulphur treatments (Table 4.4). The S content in grain ranged from 0.135% to 0.170% due to sulphur application. The maximum S content (0.170%) was found in S_2 treatment and the minimum (0.135%) was in S_0 treatment (Figure 4.23). The S content increased gradually with the application of different levels of sulphur. The results is in agreement with the findings of Chandal *et al.*, (2003) that increasing S levels in rice significantly increased S content in rice up to 45 kg S ha^{-1}.

The single effect of boron on S content in rice grain was also significant (Table 4.5). The maximum S content (0.174%) was recorded in B_1 treatment and the minimum (0.140%) was in B_0 treatment (Figure 4.24). It was observed that S content in rice grain decreased with further increase in B level.

The interaction effect of sulphur and boron on S content in rice grain was significant. The S content in straw increased due to the combination treatments of sulphur and boron ranged from 0.125% to 0.189%. The highest S content was observed in S_2B_1 treatment and the lowest was in S_0B_0 treatment (Table 4.6).

4.2.8 Sulphur content in straw

In the straw of BRRI dhan 30, the S content was influenced significantly by the single application of different levels of sulphur (Table 4.4). The highest S content (0.136%) was found in S_2 treatment which was statistically similar to S_1 and S_3 treatments. The lowest S content (0.116%) was found in control (Figure 4.23). The result support the findings of Islam *et al.*, (2006) who reported that application of S had increase the concentration of S in straw.

The single effect of boron on S content in rice straw in statistically significant (Table 4.5). The highest S content (0.136% was found in B_2 treatment which was statistically identical to B_1 treatment. The lowest S content (0.124%) was found in control (Figure 4.24).

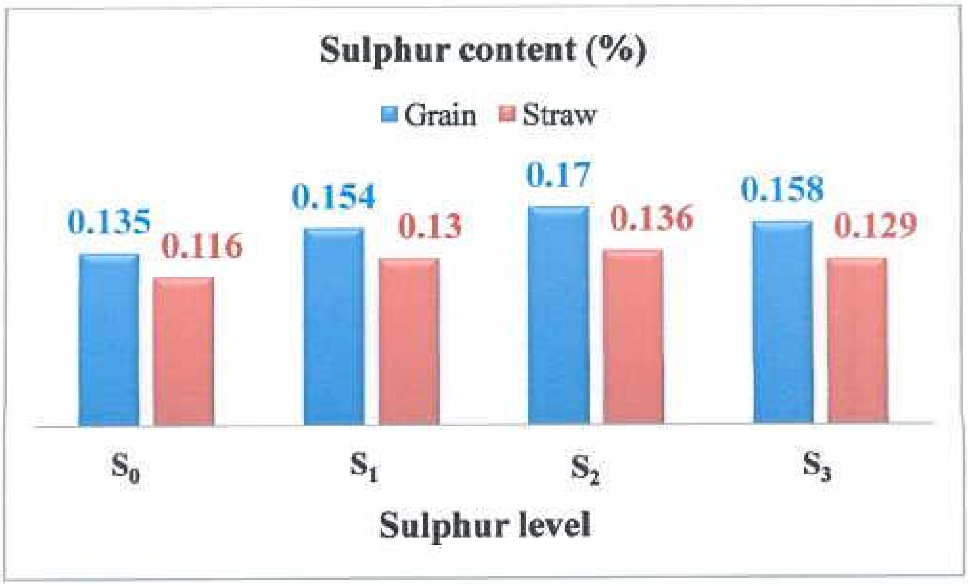


Figure 4.23 Effect of different levels of sulphur on sulphur content of grain and straw of BRRI dhan 30

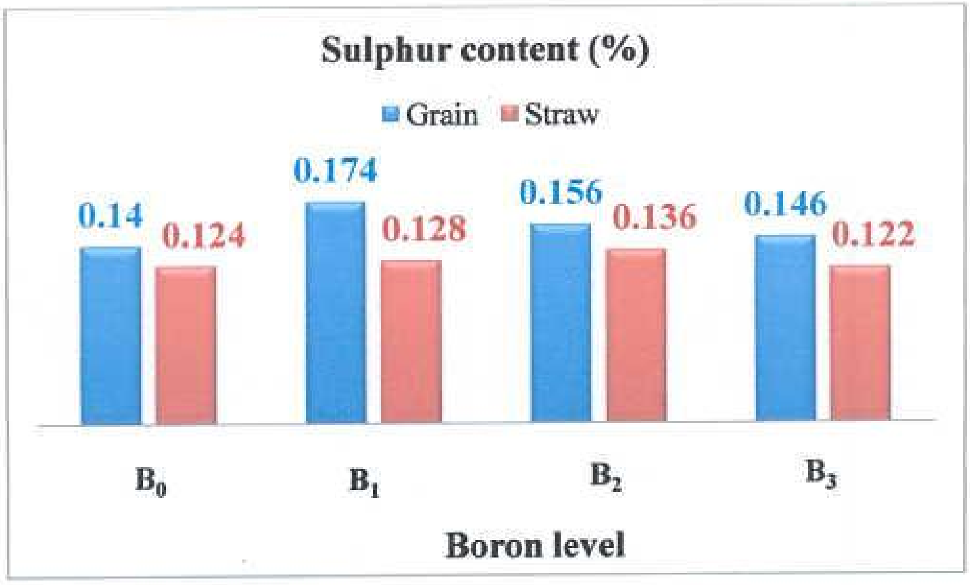


Figure 4.24 Effect of different levels of boron on sulphur content of grain and straw of BRRI dhan 30

The interaction effect of sulphur and boron on S content in rice grain was not significant on the S content of rice straw. Due to the combined treatments of S and B the S content ranged from 0.103% to 0.141%. The highest S content in rice straw was recorded in S_2B_1 treatment and the lowest was found in S_0B_0 treatment (Table 4.6).

4.2.9 Boron content in grain

It was evident from the results presented in (Table 4.4) that the application of sulphur had significant effect on the accumulation of boron in rice grain. The maximum boron content (15.98 $\mu g\ g^{-1}$) in rice grain was obtained in S_2 treatment which was statistically identical to S_1 treatment and the lowest (13.31 $\mu g\ g^{-1}$) was found in S_0 treatment (Figure 4.25).

The concentration of B in the grain of BRRI dhan 30 was influenced significantly by the application of boron (Table 4.5). The maximum B content (16.93 $\mu g\ g^{-1}$) was found in B_1 treatment and the minimum (10.79 $\mu g\ g^{-1}$) was in B_0 treatment (Figure 4.26). It can be seen that with increase in level of B its accumulation in rice grain remarkably increased.

The interaction effect of sulphur and boron on B content in rice grain was also statistically significant in the respect of boron content in rice grain. The B content ranged from 10.16 $\mu g\ g^{-1}$ to 18.76 $\mu g\ g^{-1}$. The highest B content in rice grain was recorded in S_2B_1 treatment and the lowest was found in S_0B_0 treatment (Table 4.6).

4.2.10 Boron content in straw

Data show (Table 4.4) that B content in straw varied significantly due to the applied sulphur levels. The highest B concentration (14.95 $\mu g\ g^{-1}$) was found in S_2 treatment while the lowest (10.84 $\mu g\ g^{-1}$) was in S_0 treatment (Figure 4.25).

The concentration of boron was also significantly influenced by the application of boron (Table 4.5). The maximum boron content (16.04 $\mu g\ g^{-1}$) was observed in B_1 treatment and the minimum B content was found in B_0 treatment (Figure 4.26).

The interaction effect of sulphur and boron showed statistically significant influence on boron content of straw. The B content ranged from 10.84 $\mu g\ g^{-1}$ to 17.93 $\mu g\ g^{-1}$. The highest B content in rice straw was found in S_2B_1 treatment and the lowest was found in S_0B_0 treatment (Table 4.6).

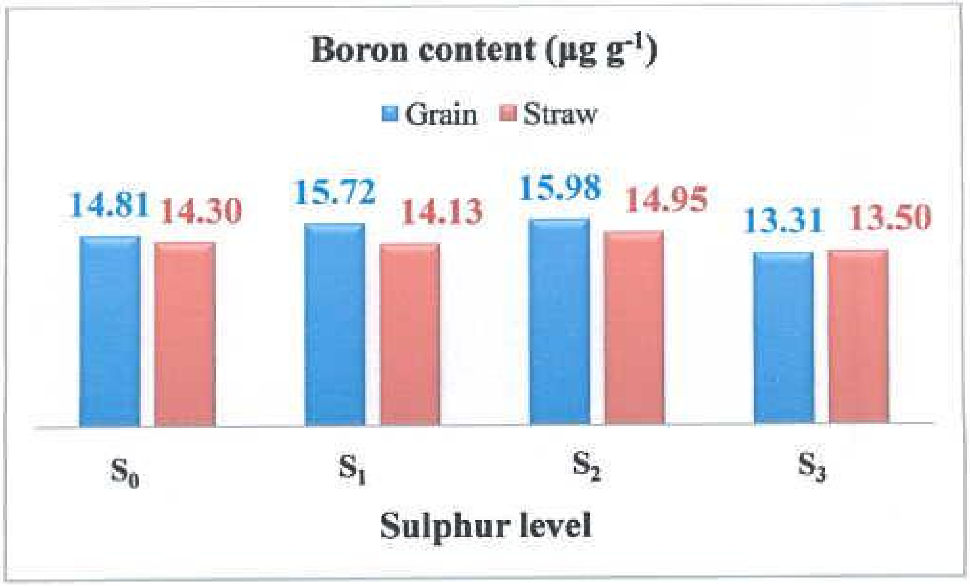


Figure 4.25 Effect of different levels of sulphur on boron content of grain and straw of BRRI dhan 30

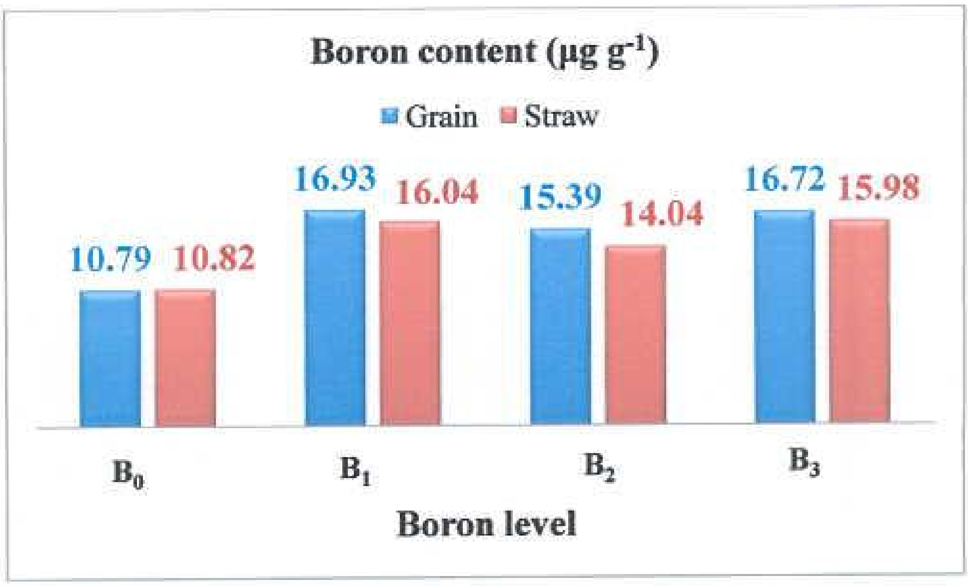


Figure 4.26 Effect of different levels of boron on boron content of grain and straw of BRRI dhan 30

4.3 Correlation and regression studies

Different correlation matrix and regression lines have been shown in Table 4.7 and Figure 4.27 to 4.33.

4.3.1 Grain yield and effective tiller hill^{-1}

There is a direct significant and positive relationship between grain yield and effective tiller hill^{-1} of BRRI dhan 30 which has been confirmed with correlation co-efficient r = 0.607* (Figure 4.27). The relationship was more evident when the equation Y = 0.1846 X+ 2.8167 which show gradual increase in grain yield with the increase of effective tiller hill^{-1}

4.3.2 Grain yield and panicle length

The relationship between grain yield and panicle length of BRRI dhan 30 has been found out. The correlation co-efficient (r =0.643*) was significant at 5% level of probability. The line regression of Y (grain yield) on X (panicle length) having equation Y = 0.264 X – 01.3566 is shown in Figure 4.28 and Table 4.7. The positive slope indicates that the grain yield and panicle length is directly correlated i.e. increase in grain yield result in increase in panicle length.

4.3.3 Grain yield and weight of 1000-grains

There is a positive relationship but non significant between grain yield and weight of 1000-grains of rice cv. BRRI dhan 30 which have been confirmed with correlation co-efficient r = 0.444^{NS} (Figure 4.29 and Table 4.7). The relationship was more evident when the equation Y = 0.229X – 0.5687 which show gradually increase in grain yield with the increase of weight of 1000-grains are directly correlation i.e. increase in nitrogen content result in increase in boron content and vise-versa.

4.3.4 Grain yield and straw yield

There is a direct significant and positive relationship between grain yield and straw yield of rice cv. BRRI dhan 30 which have been confirmed with correlation co-efficient r = 0.808* (Figure 30). The relationship was more evident when the equation Y = 0.5439 X+ 0.8615 which show gradually increase in grain yield with the increase of straw yield.

4.3.5 Grain yield and nitrogen content

Experimental results revealed that grain yield showed significantly positive correlation with its nitrogen content (r= 0.639*). This relationship indicates that higher grain yield is one of the most important factors in obtaining higher nitrogen content. The regression equation of Y (grain yield) on X (nitrogen content) was found to be Y = 4.5411 X – 0.775 (Figure 4.31 and Table 4.7).

4.3.6 Grain yield and sulphur content

Experimental results revealed that grain yield showed significantly positive correlation with its sulphur content (r= 0.787*). This relationship indicates that higher grain yield is one of the most important factors in obtaining higher sulphur content. The regression equation of Y (grain yield) on X (sulphur content) was found to be Y = 15.914 X + 2.1818 (Figure 4.32 and Table 4.7).

4.3.7 Grain yield and boron content

Experimental results revealed that grain yield showed significantly positive correlation with its boron content (r= 0.639*). This relationship indicates that higher grain yield is one of the most important factors in obtaining higher boron content. The regression equation of Y (grain yield) on X (boron content) was found to be Y = 0.7166 X – 0.7024 (Table 4.7).

4.3.8 Nitrogen content and sulphur content

Experimental results revealed that percent nitrogen content showed significantly positive correlation with its sulphur content (r= 0.872**). This relationship indicates that higher nitrogen content is one of the most important factors in obtaining higher sulphur content. The regression equation of Y (nitrogen content) on X (sulphur content) was found to be Y = .078 X + 0.8818 (Figure 4.33 and Table 4.7).

4.3.9 Nitrogen content and boron content

Experimental results revealed that percent nitrogen content showed significantly positive correlation with its boron content (r= 0.261*). This relationship indicates that higher nitrogen content is one of the most important factors in obtaining higher boron content. The regression equation of Y (nitrogen content) on X (boron content) was found to be Y = 0.0048 X + 1.1198 (Table 4.7).

Table 4.7 Relationship between agronomic characters, nitrogen, sulphur and boron content of rice

Correlation characters	Correlation co-efficient	Regression equation $Y = A + BX$
Grain yield Vs effective tiller $hill^{-1}$	r = 0.607 *	Y = 2.8167 + 0.1846X
Grain yield Vs panicle length	r = 0.643 *	Y = 0.264 X – 01.3566
Grain yield Vs weight of 1000-grain	r = 0.444 ^{NS}	Y = 0.229X – 0.5687
Grain yield Vs straw yield	r = 0.808 **	Y = 0.5439 X+ 0.8615
Grain yield Vs nitrogen content	r = 0.639 *	Y = 4.5411 X – 0.775
Grain yield Vs sulphur content	r = 0.787 *	Y = 15.914 X + 2.1818
Grain yield Vs boron content	r = 0.639 *	Y = 0.7166 X – 0.7024
Nitrogen content Vs sulphur content	r = 0.872 **	Y = .078 X + 0.8818
Nitrogen content Vs boron content	r = 0.261*	Y = 0.0048 X + 1.1198

* → Significant at 5% level of probability

** → Significant at 1% level of probability

NS → Non significant

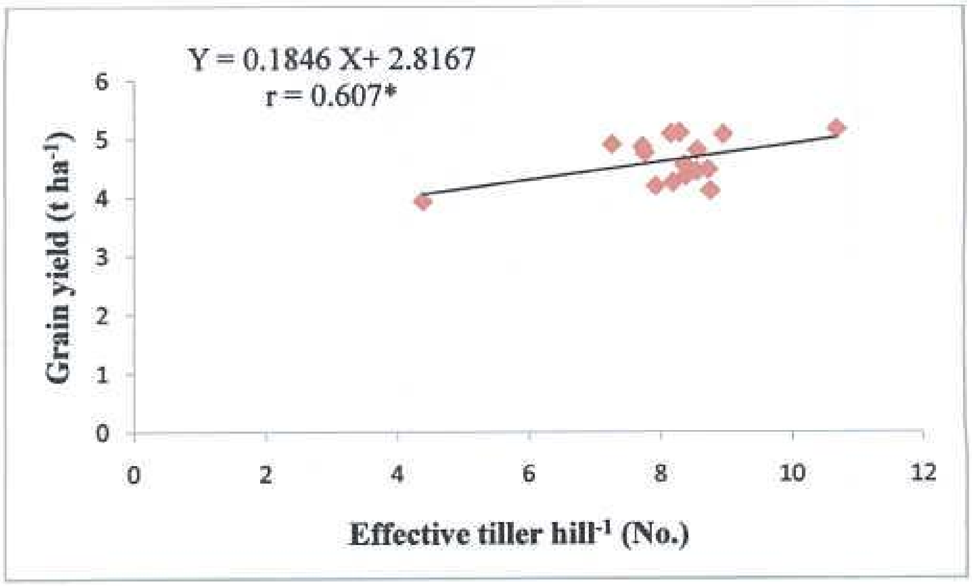


Figure 4.27 Relationship between grain yield and effective tiller hill^{-1} of BRRI dhan 30

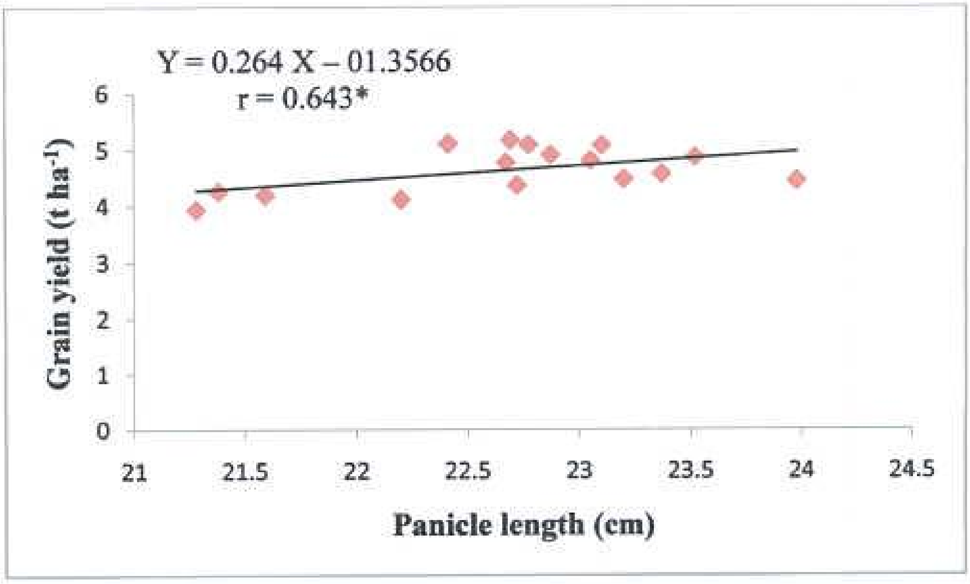


Figure 4.28 Relationship between grain yield and panicle length of BRRI dhan 30

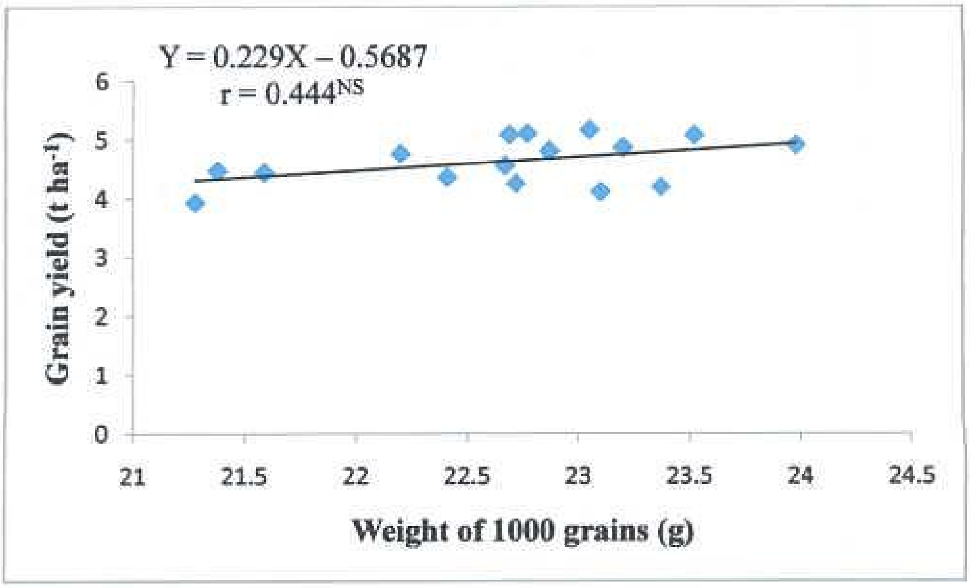


Figure 4.29 Relationship between grain yield and weight of 1000 grains of BRRI dhan 30

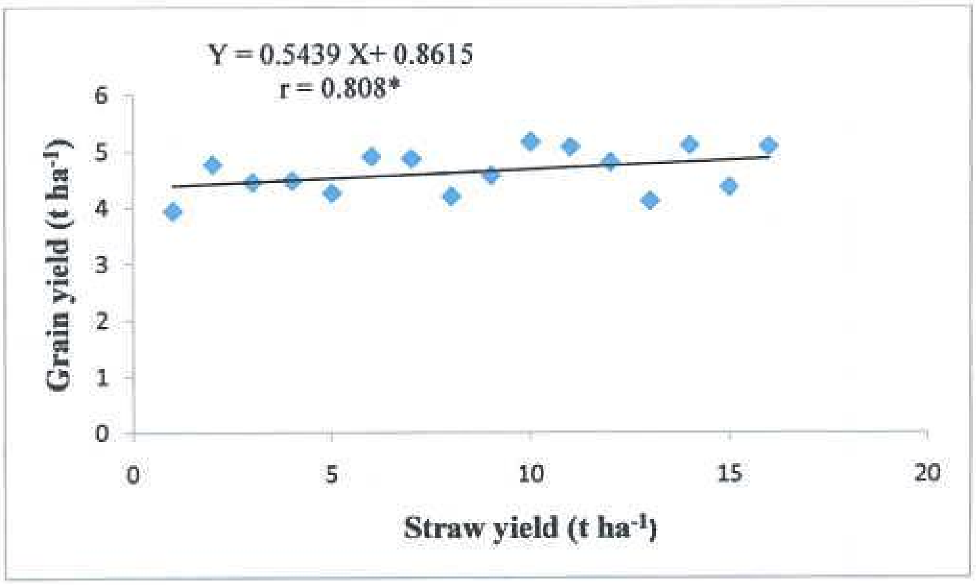


Figure 4.30 Relationship between grain yield and straw yield of BRRI dhan 30

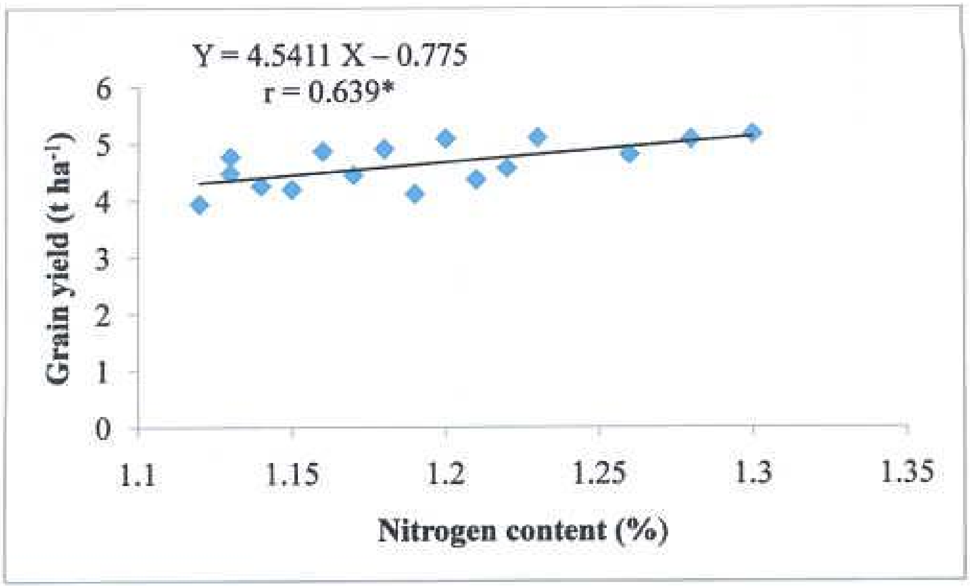


Figure 4.31 Relationship between grain yield and nitrogen content of BRRI dhan 30

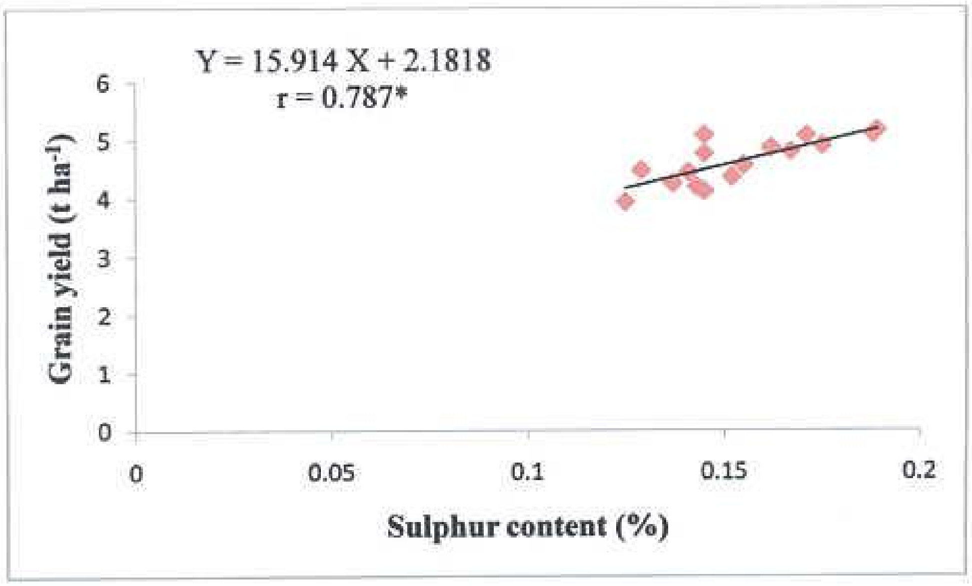


Figure 4.32 Relationship between grain yield and sulphur content of BRRI dhan 30

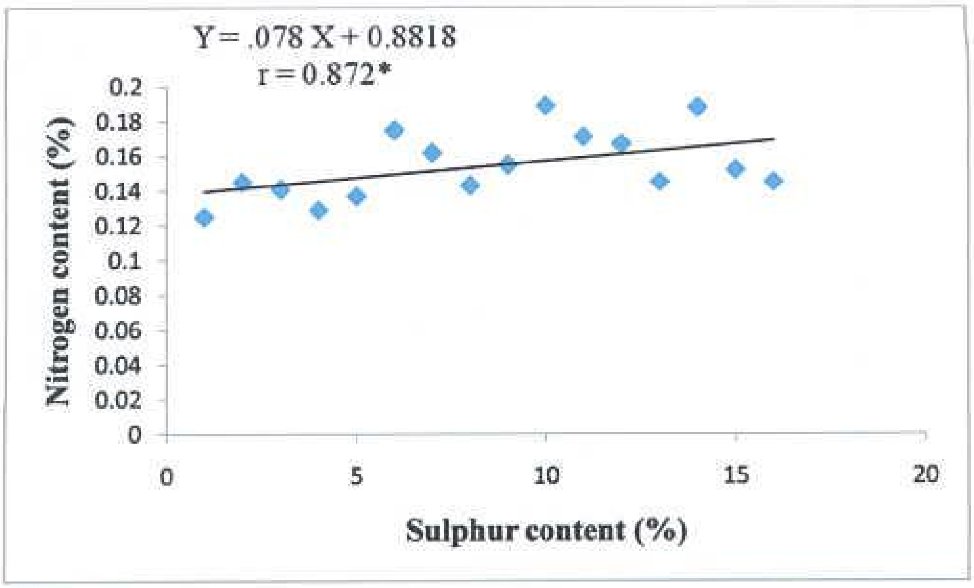


Figure 4.33 Relationship between nitrogen content and sulphur content of BRRI dhan 30

CHAPTER V

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the experimental farm of Sher-e-Bangla Agricultural University, Dhaka during the period from July to November, 2011 to evaluate the effect of added sulphur, boron and their interaction on yield and nutrient content of BRRI dhan 30. Thirty days old seedlings of BRRI dhan 30 was transplanted on 24^{th} July 2011 and was harvested on 24^{th} November 2011.

The soil of the experiment field belongs to the agro-ecological zone of Madhupur tract (AEZ- 28). The experiment comprised of 16 treatments consisting of 4 levels of sulphur (0, 8, 12, 16 kg S ha) and 4 levels of boron (0, 1, 1.5, 2 kg B ha). The source of sulphur and boron are gypsum and borax respectively. The experiment was laid out in the Randomized Completely Block Design (RCBD) with 3 replications. The size of unit plot was (2 x 2) m^2 and the number of total plots was 48. The experimental plot was fertilized with urea, TSP, MOP and zinc sulphate. Sulphur and boron was applied with TSP, MOP and zinc sulphate one day prior to transplanting during the final land preparation. Urea was applied in three splits. The intercultural operations such as irrigation, weeding, ail repairing and application of insecticides were done as and when needed

The pre-planting soil samples were collected from 10 spots of the experimental plot at a depth of 0-15 cm and chemically analyzed. After the crop had been harvested from each unit plot at maturity, the yield and yield contributing characters were recorded. Nitrogen, phosphorus, potassium, sulphur and boron contents of rice grain and straw were studied. The collected and calculated data were analyzed statistically.

Due to S additions the yield contributing characters of BRRI dhan 30 were significantly affected except the plant height. Three levels of S treatment significantly increased the number of effective tillers $hill^{-1}$ while the significantly decreased the number of non-effective tillers $hill^{-1}$. However, the highest number of effective tillers $hill^{-1}$ (9.09) was observed in 12 kg S ha^{-1} (S_2) treatment. Similarly S treatment significantly increased the number of filled grain but decreased number of unfilled grains $panicle^{-1}$. It may be noted that 12 kg S ha^{-1} treatment resulted in the highest number of filled grains (102.42) $panicle^{-1}$ and consequently the lowest number of unfilled grains (9.01) $panicle^{-1}$. Addition of S seemed to have increased significantly the panicle length of rice and the highest (25.64 cm) being observed in 12 kg S ha^{-1} treatment. The, weight of 1000-grains was found to be significantly increased by S treatment, the highest (23.31 g) being given by 12 kg S ha^{-1} treatment. However, the increase of 1000 grain weight was similar in 8 kg and 16 kg S ha^{-1} treatments.

The grain yield of rice was significantly augmented by the added S, the highest (4.89 t ha^{-1}) being produced by 12 kg S ha^{-1} treatment. As per as straw yield is concerned, there was no effect of 8 kg S ha^{-1} treatment in comparison with the control although 16 kg S ha^{-1} treatment was found to have significantly increased the straw yield.

Addition of B seemed to have no effect on number of unfilled grains $panicle^{-1}$, and 1000-grain weight. Unlike S, B was found to have significantly increased the plant height, the highest (117.07crn) being observed in 1.5 kg B ha^{-1} treatment. The number of effective tillers hil^{-1} was also significantly increased while the number of non-effective tillers hil^{-1} was significantly decreased by B treatments. Addition of B seemed to have increased significantly the panicle length of rice and the highest (25.73 cm) being observed in 1 kg B ha^{-1} treatment. The significantly highest number of filled grains (97.60) was produced by 1.00 kg B ha^{-1} treatment. Both grain and straw yields were significantly increased by the B treatment, the highest (4.99 t ha^{-1}), (7.08 t ha^{-1}) being given by 1 kg B ha^{-1} treatment followed by 1.5 kg B ha^{-1} and 2 kg B ha^{-1} treatment.

The combined application of S and B significantly increased the number of effective tillers $hill^{-1}$, Panicle length, grain and straw yields of rice. The highest number of effective tillers $hill^{-1}$ (10.70), the highest panicle length (26.02) and the highest grain and straw yields were found in (12 kg S + 1 kg B ha^{-1}) treatment. All other yield contributing characters were non-significantly affected by the S and B interaction except the number of unfilled grain $panicle^{-1}$ which significantly decreased by their combined treatments.
The nutrient content (N, P, K, S and B) of rice grain and straw was studied and their results were analyzed. Different levels of sulphur showed significant effect on N content

in rice grain and straw where the highest and lowest contents of N was observed in S_2 and S_0 treatments respectively. Different boron levels showed significant effect on N content in grain and straw. Significant effect was also noted due to the combined effect of sulphur and boron in rice grain and straw.

Different levels of sulphur showed significant effect on P content in rice grain and straw where the highest (0.31%) and lowest (0.25%) contents of P was observed in S_2 and S_0 treatments respectively. Different boron levels showed significant effect on P content in grain and straw. Significant effect was also noted due to the combined effect of sulphur and boron in rice grain and straw.

Potassium content in rice grain and straw was significant by the effect of sulphur and boron. In rice grain and straw S_3 produced the highest (0.73%) and (1.78%) content of K and S_0 produced the lowest (0.62%) and (1.48%) respectively. Different levels of boron showed significant effect on K content in rice grain and straw where the highest (0.71%) and (1.785%) lowest (0.67%) and (1.495%) contents of K was observed in B_1 and B_0 treatments respectively.

The S content in rice grain was significant by the effect of sulphur and boron but their interaction effect failed to show significant effect in rice straw. In rice grain S_2 produced the highest (0.170%) content of sulphur and S_0 produced the lowest (0.135%). The S content in rice grain ranged from 0.125% to 0.189%. In the straw the effect was significant in sulphur and boron treatments. The highest sulphur content (0.136%) was recorded in S_2 treatment and the lowest (0.116%) in control treatment. The S content in rice straw ranged from 0.103% to 0.141%. The treatment combination that produced highest and lowest sulphur content in grain was S_2B_1 and S_0B_0 treatment where in case of straw was S_2B_1 and S_0B_0 treatment respectively.

Boron content in rice grain and straw was influenced significantly by the application of different sulphur and boron levels in all cases. Due to application of sulphur the highest (15.98 μg g^{-1}) boron content in grain was observed in S_2 and lowest (13.31 μg g^{-1}) in S_3 level while the highest (14.95 μg g^{-1}) by S_2 and lowest (13.50 μg g^{-1}) boron content by S_3 was observed in straw. Different boron levels showed significant effect on boron content in rice grain and straw. The interaction effect of sulphur and boron was also found to be significant in respect to boron content in rice grain and straw. B content in rice grain and straw ranged from 10.16 to 18.76 $\mu g\ g^{-1}$ and 10.84 to 17 .93 $\mu g\ g^{-1}$ respectively due to interaction effect of sulphur and boron application.

Most of the nutrients content was found to vary significantly due to sulphur application but not significant with boron. The reason might be due to the deficiency of sulphur in pre-planting soil but not in boron. Moreover, the interaction of sulphur and boron was synergistic at lower concentration but antagonistic at higher concentration.

From the result of present investigation it was evident that application of sulphur and boron augmented the agronomic and nutrients content in rice. In order to achieve higher yield and nutrient content of rice it is advisable that 12.0 kg S $ha^{-1}$and 1 kg B ha^{-1} to be employed with the basal doses of other essential nutrients particularly in soils alike that under study.

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

1. Such study is needed to be conducted in different agro-ecological zones (AEZ) of Bangladesh for regional adaptability and other performances
2. The level of S and B and time of application may be included in the further study
3. Other fertilizer or combined fertilizer may also be included in the program for future study.

REFERENCES

REFERENCES

AARI. Annual Report. (2000). Rice response to micronutrient. Ahmedabad Agricultural Research Institute. Faisalabad, India. Pp.180.

Abraham, G. (2000). Interactive effect of sulphur and nitrogen on some physiological parameters of mustard (Brassica Juncea L.Czern. and Coss.). Deparment of Botany, Hamdard University, New Delhi, India.Cruciferae-news letter. No. 22: 65-66.

Abul, H. Md. Shamim, Md., Harunor, R. K. and Takeo, A. (2008). Impacts of sulfidic materials on the selected major nutrient uptake by rice plants grown in sulfur deficient soils under pot experiment. *J. of American Sci.* **4**(3): 68-74.

Ahmed, S. and Hossain, M.B. (1997). The problem of boron deficiency in crop production in Bangladesh.In. Boron in soils and plants Eds. R.W. Bell and Rerkasem, Kluwar Acadic Publishers, Netherlands. Pp. 1-5.

Akram, M.S., Ali, Q., Athar, H. and Bhatti, A.S. (2006). Ion uptake & distribution in Panicum antidotale Retz., under salt stress. *Pak. J. Bot.* **38**: 1661-1669.

Alam, M.K., Sayem, S.M.,Rahman, M. N., Islam, M.S. and Mondol, A.T.M.A.I. (2007). Influence of Sulphur on Nutrient Content and Uptake by Rice and Its Balance in Old Brahmaputra Floodplain Soil. *J.Soil.Nature.* **1**(3): 5-10.

Alamdari, M.G., Rajurkar, N.S., Patwardhan, A.M. and Mobasser, H.R. (2007). The effect of sulfur and sulfate-fertilizers on Zn and Cu uptake by the rice plant (*Oryza sativa*). *Asian J. for Plant Sci.* **6** (2): 407-410.

Ali, M.M., Mian, M.S., Ilam, M., Begum, J.A. and Ferdous, A.K.M. (2004). Interaction effects of sulphur and phosphorus on wetland rice. *Asian J. for Plant Sci.* **3**(5): 597-601.

Alloway, B.J. (2008). Micronutrient deficiencies in global crop production. Springer Science+ Business Media, B.V, Netherlands. Pp. 130.

Amitava, R., Bhadoria, P.B.S., Ghosh, D. and Pakshit, A. (2002). Influence of boron on NPK uptake of rice (Oryza sativa L.) in acid alluvial soils of Coochbehar. Environment and Ecology. **20** (1): 188-190.

Anonymous. (2003). Boron Fact Sheet. Incitec Pivot Limited 70, Southbank Bvd, Melbourne 3006. www.incitecpivot.com.au.

Babu, S.N.S. and Hedge, D.M. (2002). Delineation of sulphur deficient soil and evaluation of oil seed crops response to sulphur. Fertilizer Marketing News. **33** (3): 9-17.

Badruddin, M. (1999). The effect of sulphur deficiency on ion accumulation with special reference to 15N and 35S transport and metabo1ism in chickpea *(Cicer arietinum L.)*.Ph.D. Thesis, Dhaka University, Dhaka, Bangladesh.

Banglapedia.(2003). National Encyclopedia of Bangladesh. Asiatic Society of Bangladesh. **8** : 417.

BARC (Bangladesh Agriculture Research Council) (2000). Fertilizer Recommendation Guide. Bangladesh Agricultural Research Council, Farmgate, New Airport Road, Dhaka 1215. Pp.132.

Basumatary, A. and Talukdar, M.C. (2007). Integrated effect of sulphur and farmyard manure on yield and mineral nutrition of crops in rapeseed (*Brassica napus*) – rice (*Oryza sativa*) sequence. *Indian J. Agric. Sci.* **77** (12): 797-800.

BBS (Bangladesh Bureau of Statistics) (2011). Monthly Statistical Bulletin, Bangladesh. June, 2011. Planning Div., Ministry of Planning, Government of the Peoples' Republic of Bangladesh. Dhaka: 57-143.

BBS (Bangladesh Bureau of Statistics) (2008). Monthly Statistical Bulletin, Bangladesh. July, 2008. Planning Div., Ministry of Planning, Government of the Peoples' Republic of Bangladesh. Dhaka. Pp. 50-60.

Bellaloui, N., Yadavc, R.C. and Chern, M. S. (2003). Transgenically enhanced sorbitol synthesis facilitates phloem boron mobility in rice. Physiologia Plantarum **117**(1): 79-84.

Benton, J.J. (2003). Agronomic handbook; management of crops, soil sand their fertility. CRC press LLC. USA. Pp. 75-80.

Bhuvaneswari, R., Sriramachandrasekharan, M.V. and Ravichandran, M. (2007). Effect of organics and graded levels of sulphur on rice yield. *Indian J. Inter Academica.* **11**(1): 51-54.

Black, C.A. (1965). Methods of Soil Analysis. Part I and II. American Society Agronomy Inc. Pub. Madison, Wisconsin, USA. Pp. 120, 132, 150.

Bolanos, L., Lukaszewski, K., Bonilla, I. and Blevins, D. (2004). Why boron? Plant Physiology and Biochemistry. 42: 907–912.

Brady, N.C. and Weil, R.R. (2002).The nature and properties of soils.13th edn.Pearson Education (Singapore) Ptc. Ltd., India.

Camacho-Cristobal, J.J., Maldonado, J.M and Gonzalez-Fontes, A. (2005). Boron deficiency increases putrescence levels in tobacco plants *J. Plant Physiol.* **162**: 921-928.

Chandal, R.S., Kalyan, S., Singh, A.K. and Sudhaker, P.C. (2003). Effect of sulphur nutrition in rice and mustard grown in sequence. *Indian J. Plant Physiol.* **8**(2): 155-159.

Chandel, R.S., Sudhakar, P.C. and Kalyan, S. (2003). Response of sulphur in rice - a review. *Agric. Rev.* **24** (3): 167 – 174.

Debnath, P., Chandra, G. and Sudipta K. G. (2009). Critical limit of available boron for rice under red and laterite zone of west bengle, India. *SAARC J. Agri.* **7** (1): 100-106.

Dekok, L.J., Stuiver, C.E.E., Westerman, S. and Stulen, I. (2002). Elevated levels of hydrogen sulfide in the plant environment: nutrient or toxin. In: Omasa, K., Saji, H., Youssefian, S., Kondo, N. (eds.) Air Pollution, Biotechnology in Plants. Springer-Verlag, Tokyo. Pp.201-213.

Dell, B. and Huang, L. (1997). Physiological response of plants to low boron. Plant and Soil. 193: 103–120.

Devirian, T.A. and Volpe, S.L. (2003). The physiological effects of dietary boron. Critical Reviews in Food Science and Nutrition. **43**: 219–231.

Dewal, G. S. and Pareek, R. G. (2004). Effect of phosphorus, sulphur and zinc on growth yield and nutrient uptake of rice (*Oryaza sativa*). *Indian J. Agron.* **49**(3): 160-162.

Dewal, G.S. and Pareek, R.G. (2007). Effect of boron sulphur and zinc on growth, yield and nutrient uptake of rice (*Oryza sativa*). *Indian J. Agron.* **50** (3): 160-162.

Dinesh, K., Shivay, Y.S. and Nawmar, L. (2007). Effect of nitrogen and sulphur fertilization on yield attributes, productivity and nutrient uptake of aromatic rice (Oryza sativa). *The Indian J. of Agril. Sci.* **77** (11): 211-213.

Dobbermann, A. and Fairhurst, T. (2000). Rice-nutrient disorder & nutrient management.1st edi. Potash & Phosphate Institute of Canada and International Rice Research Institute. Pp. 40-117.

Dunn, D., Stevers, G. and Kendig, A. (2005). Boron fertilization of rice with soil and foliar applications online crop management doi: 10.1094/ crn 2005-2010-01-RS.

Dunn, D. and Jones, S. (2001). Boron Fertilization of Rice. Missouri Rice Research Institute. Pp. 40-45.

Ehsan, U. H. M., Rizwana, K., Muhammad, A. And Sher, M. S. (2009). Is boron required to improve rice growth and yield in saline environment? *Pak. J. Bot.* **41**(3): 1339-1350.

FAO (Food and Agriculture Organization) (2002). Production Year Book of 2002.No. 61. Published by Food and Agricultural Organization, Rome, Italy. Pp. 76-77.

FAO (Food and Agriculture Organization) (2003). Production Year Book of 2003.No. 62. Published by Food and Agricultural Organization, Rome, Italy.Pp. 54.

Ghatak, R., Jana, P.K., Sounda, G., Ghosh, R.K. and Bandyopadhyay, P. (2006). Effect of boron on yield, concentration and uptake of N, P and K by rice grown in farmer's field on red and laterite soils of Purulia, West Bengal. Indian-Agriculturist. **50** (1-2): 15-77.

Goldbach, H.E. and Wimmer, M. (2007). Boron in plants and animals: Is there a role beyond cell-wall structure? *J. Plant Nutr. Soil Sci.* **170**: 39-48.

Goldbach, H.E., Yu, Q., Wingender, R., Schulz, M., Wimmer, M., Findeklee, P. and Baluska, F. (2001). Rapid response reactions of roots to boron deprivation. *J. Plant Nutr. Soil Sci.* **164**: 173-181.

Goldberg, S. and Chuming, S. (2007). New advances in boron soil chemistry. Xu, F. *et al* (ed.) Advances in Plant and Animal Boron Nutrition, Springer Science+ Business Media B.V, Netherlands. Pp. 313-330.

Gonzalez-Fontes, A., Rexach, J., Navarro-Gochicoa, M.T., Herrera-Rodríguez, M.B., Beato, V.M., Maldonado, J.M. and Camacho-Cristobal, J.J. (2007). Is boron involved solelyin structural roles in vascular plants? *Plant Signal. Behav.* **3**:24-26.

Gupta, S.P., Gupta, U.K. and Ramkala. (1999). Extractants and critical limit of available sulphur in arid soils. *J. Indian Soil Sci.* **43** (3): 478-479.

Haque, S. A. and Chowdhury, L. (2004). Effects of rice straw and sulphur on the growth and yield of rice. *J. Bangladesh Agril. Univ.* **2** (1): 5-18.

Haque, M.S. and Jahiruddin, M. (1999). Effect of single and multiple applications of sulphur and zinc in a continuous rice cropping pattern. *Indian J. Agric. Res.* **28**(1): 9-14.

Hasnat, A. Md., Shamim, Md., Rashid, H. K. and Takeo, A. (2008).Impacts of sulfidic materials on the selected major nutrient uptake by rice plants grown in sulfur deficient soils under pot experiment. *J. of American Sci.* **4** (3): 68-74.

Havlin, J.L., Beaton,J.D., Tisdale, S.L. and Nelson, W.L. (2004). Soil fertility and fertilizers, An introduction to nutrient management. Singapore: Pearson Education. Pp.25-28.

Hawkesford, M.J. (2000). Plant responses to sulphur deficiency and the genetic manipulation of sulphate transporters to improve S-utilization efficiency. *J. of Experimental Botany.* **51**: 131-138.

Hegde, D.M. and Babu, S.S.N. (2007). Correcting sulphur deficiencies in soils and crops. *Indian J. Fert.* **3**(1): 65-79.

Hitsuda, K., Yamada, M. and Klepker, D. (2005). Sulfur requirement of eight crops at early stages of growth. *Agronomy J.* **97**:155-159.

Hossain, M.A., Jahiruddin, M., Hoque, M.S. and Ali, M.L (1999). Effect of genotype and sowing date on the responses to boron in wheat. *Pak. J. Sci. and Indu. Res.* **37**(10): 432-435.

Hosseini, S.M., Maftoun, M.,Karimian, N., Ronaghi, A. and Emam, Y. (2005). Effects of different levels of boron and zinc, and two zinc sources on rice growth and chemical composition. *Iranian J. Agric. Sci.* **36** (4): 869-883.

Huda, M.N., Islam, M.N. and Jahiruddin, M. (2004). Evaluation of extractants and critical limits of sulphur in rice soils of Bangladesh. *Asian J. of plant Sci.* **3**(4): 480-483.

Hussain, F. and Yasin, M. (2004). Soil fertility monitoring and management in Rice wheat system. Annual Report, LRRP, NARC, Islamabad. Pp.1-33.

Indira, C. (2006). The effect of micronutrients on yield attributes, yield and nutrient uptake of hybrid rice (*Oryza sativa* L.) *Asian J. of Bio Sci.* **1**(2): 89-91.

IRRI (International Rice Research Institution) (1995). World Rice Statistics, 1993-94. Intl. Rice Res. Inst., Manila, Philipines. pp. 2-19.

Islam, M.N., Ara, M.J., Hossain, M.M., arefin, M.S. and Hossain, G.M.A. (2006). Effect of different dates of gypsum application on the nutrient content of T. aman rice. *Int. J. Sustain. Agric. Tech.* **2** (6): 5-8.

Islam, M.R. and Hossain, A. (1998). Influence of additive nutrients on the yield of BR 11 rice. *Thai. J. Agril. Sci.* **26**: 195-199.

Islam, M.R., Alam, M.N. and Hashem, M.A. (1995). Enhancement of blue green algal growth and yield of BR 11 rice under different levels of soil fertility. *Progress Agric.* **6** (2): 83-89.

Islam, M.R, Risat, T.M. and Jahiruddin, M. (1997). Direct and residual effects of S, Zn and B on yield, nutrient uptake in a rice-mustard cropping system. *J. Indian Soc. Soil Sci.* **45** (1): 126-129.

Islam, M.S., Islam, M.Z., Rahman G.K.M.M. and Chowdhury M.A.A.H (2010). Effect of some secondary and micro nutrients along with organic amendments on T. aman. *Int. J. Sustain. Crop Prod.* **5** (4): 51-58.

Islam, M.R., Shah,M.S. and Jahiruddin, M. (2009). Effects of different rates and sources of sulphur on the growth and yield of BRRI dhan30. *Bangladesh Res. Pub. J.* **2**(1): 397-405.

Islam, M.S. (2009). Challenges for Nutrient Management in Bangladesh. Proc. Int. Symp. on Potassium role and benefits in improving nutrient management for food production and reduced environmental damages, Nov. 5-7. Bhubaneswar, Orissa, India. Pp.15-16.

Issa, P. and Sharma, S. N. (2006). Effect of levels and sources of sulphur on yield attributes, yield and quality of Indian rice (*Oryza sativa L.*). *Indian J. Agron.* **51**(3): 217-220.

Jackson, M.L. (1973). Soil Chemical Analysis. Prentice-Hall of India Pvt. Ltd., New Delhi, India. Pp.41-196.

Jahiruddin, M., Islam, M.N., Hashem, M.A. and Islam, M.R. (1995). Influence of sulphur, zinc and boron on yield and nutrient uptake of BR 2 rice. *Progress Agric.* **5**(1): 61-67.

Jahiruddin, M. and Islam, M.R. (2009). Effects of different rates and sources of sulphur on the growth and yield of BRRI dhan30. *Bangladesh Res. Pub. J.* **2** (1): 397-405.

Jamal, A., Fazli, I.S., Ahmad, S., Abdin, M.Z. and Yun, S.J. (2005). Effect of sulphur and nitrogen application on growth characteristics, seed and oil yield of soybean cultivars. *Korean J. Crop Sci.* **50** (5): 340-345.

Jamal, A., Fazli, I.S., Ahmad, S., Kim, K.T., Oh, D.G and Abdin, M.Z. (2006). Effect of sulfur on nitrate reductase and ATP sulfurylase activities in groundnut (*Arachis hypogea* L.). *J. Plant Biology.* **49** (6): 513-517.

Jana, P.K., Ghatak, R.,Sounda, G., Ghosh, R.K. and Bandyopadhyay, P. (2005). Effect of boron on yield, content and uptake on NPK by transplanted rice at farmer's field on red and laterite soils of West Bengal. *J. of Inter academicia.* **9** (3): 341-344.

Javaid, A.S., Memon, M.Y., Aslam, M., Depar, N., Sial, N. and Khan, P. (2011). Response of two rice varities viz., Khushboo-95 and Mehak to different levels of boron. *Pak. J. Bot.* **43** (2): 1021-1031.

Jena, D., Sahoo, R., Sarangi, D. R. and Singh, M. V. (2006). Effect of different sources and levels of sulphur on yield and nutrient uptake by groundnut-rice cropping system in an Inceptisol of Orissa. *J. Indian Soc. Soil Sci.* **54**(1): 126-129.

Kabata, P. and Pendias, H. (2001). Trace elements in soils and plants, CRE Press, Inc.

Kabir, M.A. (2003). Boron toxicity of irrigation water and its interaction with other nutrients in three varieties of rice. MS thesis. Department of Agricultural Chemistry, BAU, Mymensingh.

Kabir, S. M., Bhuiyan, M. M. A., Ahmed, F. and Mandal, R. (2009). Effect of boron fertilization on the growth and yield of rice. *J. of Phyt. Res*. **20** (2):179-182.

Khan, H.R. (2000). Problem, prospects and future directions of acid sulfate soils. Proc. Inter. Conference on Remade Lands. Brion, A. and Bell, R.W. (ed.). Perth, Australia, Nov. 30 - Dec. 2. Pp. 66-67.

Khan, H.R., Blume, H.P., Kabir, S.M., Bhuiyan, M.M.A., Ahmed, F. and Syeed, S.M.A. (2007). Quantification of the severity, reserve and extent of acidity in the twenty profiles of acid sulfate soils and their threats to environment. Soil & Environ. 26 : 45-55.

Leustek, T. (2002). Sulfate metabolism. In CR Somerville, EM Meyerowitz, eds. The Arabidopsis Book. American Society of Plant Biologists, Rockville, MD. Pp.120.

Li-Yu. Y. and Li, Y. (2000). The characteristics of sulphur requirement and the effect of sulplhur on yield and qualities of rice.Institute of Soils and Fertilizers, Heilongijiang Academy of Agril.Sci. Heilongijiang province, China. **1**: 24-26.

Mandal, R.,Roy, P.C. and Ahmed, Z. (2000). Effect of nitrogen and sulphur on micronutrient contents of HYV rice (BR3). *J. Phyt. Res.* **13**(1): 27-:33.

Marchezan, E., Dos-Santos, O.S., De-Avila, L.A. and Da-Silva, RP. (2001). Spray application of micronutrients on irrigated rice cultivated in leveled soil. *Geneia Rural.* **31**(6): 941-945.

Marschner, H. (1995). Mineral nutrition of higher plants.2nd edi. New York, USA: Academic press. Pp.105.

Matsubayashi, Y., Ogawa, M., Morita, A. and Sakagami, Y. (2002). An LRR receptor kinase involved in perception of a peptide plant hormone, phytosulfokine. Science. **296**: 1470-1472.

MOA (Ministry of Agriculture) (1996). Bangladesh Food and Agriculture. World Food Summit, 13-17 Nov., Rome, Italy. Pp. 7.

Mortvedt J.J and Woodruff, J.R. (1995).Technology and application of boron fertilizers for crops. In: U.C. Gupta (ed.) Boron and its role in crop production. CRC Press, Boca Raton, FL. Pp. 157-176.

Mrinal, B. and Sharma, S.N (2008). Effect of rates and sources of sulphur on growth and yield of rice (*Oryza sativa*). *Indian J. Agric. Sci.***78** (3): 251-253.

Mubshar, H., Ayaz, M. K., Bismillah, M. K., Farooq, M. and Farooq, S. (2012). Boron application improves growth, yield and net economic return of rice. *J. of Rice Sci.* **19** (3): 1-8.

Nad, B.K., Purakayasha, T.J. and Singh, D.V. (2001). Nitrogen and sulphur relations in effecting yield and quality of cereals and oilseed crops. The scientific world. **381** (1): 30-34.

Naresh, P. and Jangra, K. K.(2007). Sulphur in balanced fertilization in Rajasthan. *Indian J. Fert.* **3** (2): 41-47.

Nawmarlar, Oo., Shivay, Y. S., Dinesh, K. R. P., Pandey, R. N. (2007). Effect of nitrogen and sulphur fertilization on productivity and nutrient uptake in aromatic rice. *Indian J. Fert.* **2** (11): 29-33.

Okuda, M., Isogai, A., Joyo, M., Goto-Yamamoto, N. and Mikami, S. (2009). Influence of sulfur and nitrogen content of rice grains on flavor in stored sake. *Cereal Chemistry.* **86** (5): 534-541.

Oliveira, S.S.de., Costa, M.C.G., Cbagas, R.de.C.S.,Cabral, C.P. and Malaslta, E. (2003). Response of two rice rates of zinc applied as oxysulphate. Pesquisa. Agropecuaaria, Brasibira. **38**(3): 387.

Olsen, S.R., Col, C.V., Watnable, F.S. and Dean L.A. (1954). Estimation of available phosphorus in soil by extraction with sodium bicarbonate. U.S. Dept. Agric. Cire. Pp. 929.

O'Niell, M.A., Ishii, T., Albersheim, P. and Darvill, A.G. (2004). RhamnogalacturonanII: structure and function of a borate cross linked cell wall pectic polysaccharide. Annual Review of Plant Biology. **55**: 109-139.

Onkersingh and Nandlal, J.K. (1997). Effects of sulphur deficiency on leaf area ratio and dry-matter production in sunflower *(Heliantus annus* L. var.Mordein) related with their nitrate reductase activity in leaves. *Indian J. Plant Physiol.* **30**: 368-370.

Oosterhuis, D. (2001). Physiology and nutrition of high yielding cotton in the USA. Informacoes Agronomicas N°95-Setembro. Pp. 18-24.

Oo, N.M.L., Shivay, Y.S. and Dinesh, K. (2007). Effect of nitrogen and sulphur fertilization on yield attributes, productivity and nutrient uptake of rice (*Oryza sativa*). *Indian J. Agric. Sci.*77 (11): 772-775.

Page, A.L., R.H. Miller and Keeney D.R. (ed.). (1989). *Methods of Soil Analysis.* Part-II, American Society of Agronomy, Inc. Soil Science Society of America, Inc. Madison, Wiscansin, USA. Pp. 152-340.

PCARR (Philippine Council for Agricultural Resources and Research) (1980). Standard Methods of Analysis for Soil, Tissue, Water and Fertilizer. Farm research system. Research Division, Los Banos. Philippines. Pp.11-72.

Piper, C.S. (1966). Soil and Plant Analysis. Adelaide Univ. Hassel Press, Australia. Pp.195.

Rahman, M. N., Sayem, S.M., Alam, M.K., Islam, M.S. and Mondol, A.T.M.A.I. (2007). Influence of Sulphur on Nutrient Content and Uptake by Rice and Its Balance in Old Brahmaputra Floodplain Soil. *J.Soil.Nature.* **1**(3): 05-10.

Rahman, M. T., Jahiruddin, M., Humauan, M. R., Alam, M. J. and Khan, A. A. (2008). Effect of Sulphur and Zinc on Growth, Yield and Nutrient Uptake of Boro Rice (cv. BRRI Dhan 29). *J.Soil.Nature.* **2** (3): 10-15.

Rahmatullah, K., Gurmani, A, H., Ali, R.G. and Zia, M.S. (2006). Effect of boron application on rice yield under wheat rice system. *Int. J. Agri. Biol.* **8**(6): 805-808.

Rajinder, B., Saunders, D. K. and Dell, B. (1999). Grain set failure and boron deficiency in rice in Thailand. *Thailand J. Agric.* **5** (1): 1-10.

Raju, R.A. and Reddy, M.N. (2001). Response of hybrid and conventional rice to Gliricidia loppings, sulphur and zinc application. *Fertilizer News.* **46** (11):61-62.

Rashid, A.(2006). Boron deficiency in soils and crops of Pakistan, Diagnosis and management.Booklet, PARC. Islamabad. Pp. 10-12, 20.

Rerkasem, B., Nirantrayagul, S. and Jamjod, S. (2004). Increasing boron deficiency in international bread wheat, durum wheat, triticale and barley germplasm will boost production on soil low in boron. *Field Crops Research.* **86**: 175-184.

Ribeiro, E.S., Dias, L.E., Alvarez, V.H., Mello, V.J.W.V. and Daniels, W.L. (2001). Dynamics of sulfur fractions in Brazilian soils submitted to consecutive harvests of sorghum. *Soil Sci. Soc. Americ. J.* **65**: 787-794.

Robertson, L.S., Lucas, R.E. and Christenson, D.R. (1997). Boron: An Essential Plant micronutrient. Crop Ext. Ser. Bull. E. 1037. Michigan State University.

Saito, K. (2000). Regulation of sulfate transport and synthesis of sulfur-containing amino acids.Current Opinion Plant Biology. 3: 188-195.

Sakal, R.,Singh, A.P., Choudhury, B.C. and Shahi, B. (1999). Sulphur status of ustifluvents and response to crops to sulplhur application. Fertilizer News. **46**(10): 61-65.

Sakal, R., Singh, A.p., Choudhary, B.C. and Shahi, B. (2001). Sulphur status of ustifluvents and response of crops to sulphur application. New Delhi, India: Fertilizer Association of India. Fertilizer-News. **46** (10): 61-65.

Saleem, M., Khanif, Y.M., Fauziah, I., Samsuri, A.W. and Hafeez, B. (2011). Importance of boron for agriculture productivity: A review. *Int. Res. J. of Agric. Sci. and Soil Sci.* **1**(8) :293-300.

Saliva, A. and Castilla, L.A. (2004). Response of rice to application of zinc, copper and boron on soils of high calcium content. Arroz. **43** (393): 40-43.

Samaraweera, D.N. (2009). Studies on forms and transformation of sulphur and response of rice to sulphur application in rice-rice cropping sequence. Ph.D. Thesis, University of Agricultural Sciences, Dharwad. Pp. 30.

Sarfaraz, M., Mehedi, S.M., Sadiq, M. and Hassan, G. (2002). Effect of sulphur on yield and chemical composition of rice. *Sorhad J. Agric.* **18**(4): 411-414.

Scherer, H.W. (2001). Sulphur in crop production invited paper. *Europian J. Agron.* **14**: 81-111.

Scherer, H.W. (2009). Sulfur in soils. *J. Plant Nutri. Soil Sci.* **172**: 326-335.

Schonhof, I., Blankenburg,D., Muller, S. and Krumbein, A. (2007). Sulfur and nitrogen supply influence growth, productappearance, and glucosinolate concentration of broccoli. *J. of Plant Nutri. and Soil Sci.* **170**: 65-72.

Shen, P.,Roy, P. and Bhattaacharya, B. (2002). Effect of sulphur application on yield and nutrient uptake in rice-mustard cropping system. Fertilizer Marketing News. **33**(6): 9-15.

Setia, R. K., Sharma, K. N. and Sharma, P. K., (2005). Sulphur adsorption by soil after differential fertilization for twenty-two years with NPK under a continuous maize wheat cropping systems. *J. Indian Soc. Soil Sci.* **53**(3): 417-420.

Shah, M.S., Islam, M.R. and Jahiruddin, M. (2009). Effects of different rates and sources of sulphur on the growth and yield of BRRI dhan30. *Bangladesh Res. Pub. J.* **2**(1): 397-405.

Shamim, A. H., Rashid, H. K. Md. And Akae, T. (2009). Effectiveness of sulfidic materials on the N, P, K, Mg and S nutrient uptake by rice plants grown in sulfur deficient soil under field experiment. *New York Sci. J.* **2**(4): 33-40.

Sharif, M., Ali, A.G. and Hussain, R.G. (2006). Effect of boron application on rice yield under wheat rice system. *Int. J. Agri. Biol.* **8**(6): 805-808.

Sharma, C.P. (2006). Plant Micronutrients. Science Publishers, Enfield,USA.

Sheudzhen, A. K., Aleshin, E. P. and Doseeva, O.A. (1999). The effect of trace elements on nitrogen metabolism in rice plants. **5**: 69-72.

Siddiky, MA., Halder, N.K., Ahammad, K.U., Anam, K. and Rafiuddin, M. (2007). Response of brinjal to zinc and boron fertilization. *Int. J. of Sustain. Agric. Tech.* **3**(3): 40-45.

Singh, C.S. and Singh, U.N. (2002). Effect of nitrogen and sulphur nutrition on growth and yield of rice *(Oryza sativa* L.).Cultivers Res. on Crops. **3**(3): 643-646.

Smeia, W. (2006). Studies on the effect of sulphur, zinc and boron application on the growth and productivity of transplanted rice (Oryza sativa L.). Ph.D. Thesis. Huazhong Agricultural University, Wuhan, China. Pp.31-39.

SRDI (Soil Resources Development Institute) (1999). Map of the nutrient status of sulphur and upazila land soil resource utilization guide. Pp.15-16.

Sreedevi, B., Singh, S. P. and Subbaiah, S. V. (2006). Effcet of sulfur application on conventional and hybrid rice cultivars. *Oryza,* **43**(2): 112-115.

Sriramchandrasekharan, M.V., Manivannan, R. and Ravichandran, M. (2004). Relative tolerance of rice genotypes to sulphur fertilization in sulphur deficient soil. Plant Archives. **4**(2): 427- 431.

Steel, R.G.D. and Torriee, J.H. (1960). Principles and procedures of statistics. McGraw Hill Book Company. Inc. New York. Pp.1-296.

Subbaiah, S. V., Singh, S. P., and Pillai, K. G.(2001). Effect of sulphur nutrition on grain yield of lowland rice.*Oryza.* **38**(1-2): 82-83.

Tanaka, M. and Fujiwara, T. (2007). Physiological roles and transport mechanisms of boron: perspectives from plants. *Eur. J. Physiol*. **8**(7): 370.

Tariq, M. and Mott, C.J.B. (2007). The significance of boron in plant nutrition and environment. A review. *J. Agron*. **6**: 1-10.

Tariq, M., Kakar, KM. and Shah, Z. (2005). Effect of boron and zinc interaction on the yield, yield attributes and availability of each to wheat (*Triticum aestivum* L.) grown on calcareous soils. Soil and Environment. **24**:103-108.

Tiwari, K.N. and Gupta, B.R. (2006). Sulphur for sustainable high yield agriculture in Uttar Pradesh. *Indian J. of Fertilizers*. **1**: 37-52.

Tiwari, R.J., Dwivedi, K. and Verma, S.K. (1994). Effect of gypsum application on nutrient content in cotton leaves grown on a sodic vertisol. Crop Respectively. **7**: 193-196.

Tisdale, S. L., Nelson, L.W., Beaton, D.L. and Havlin, L.J. (1999). Soil Fertility *and* Fertilizers. Prentice-Hall Pvt. Ltd. India.6^{th} edn. Pp. 220, 227-228, 319-346.

Vyas, A. K., Billore, S. D., Joshi, O. and Panchlania, N. (2006). Productivity of rice (*Oryza sativa*) genotypes as influenced by nitrogen and sulphur nutrition. *Indian J. Agric. Sci.* **76**(4): 272-273.

Wadud, M.A. (2002). Effect of Boron and Molybdenum on yield quality and nutrient uptake by BRRI dhan 30. MS Thesis. Department of Agricultural Chemistry, BAU, Myrnensingh.

Walkley, A. and Black, C.A. (1965). Determination of organic carbon. Cited from Soil and plant Analysis. Adelaide Univ. Press. Australia. Pp.195.

Wani, M.A., Rafique, M.M and Talib, A.R. (2000). Effect of different levels of sulphur on quality of rice (*Oryza sativa*). *Adv. Plant Sci.* **13** (1): 55-57.

Wrobel, S., Hrynczuk, B. and Nowak, K. (2006). Fertilization with boron as a security factor of the nutrient availability under drought condition. *Polish J. Environ. Studies.* **15**(2): 554-558.

Xiaohe, Yu. And Paul, F. B. (2008). Nutrient deficiency symptoms and boron uptake mechanism of rice. *J. of Plant Nutri.* **21**(10): 2077-2088.

Xue, Z., Meng, C.F., Lu, X., Wu, C.S and Teng, C.Qi. (2002). Effect of applying sulfur fertilizers on rice yield on paddy soils in red soil regions. Hangzhou, China: Zhejiang Academy of Agricultural Science. Acta-Agriculturae-Zhejiangensis. **14** (3): 144-149.

Xiong, H., Liu, W. and Pi, M. (1999). Effect of the interaction between boron and nitrogen on nitrogen uptake and some enzyme activity in rape. *Huazhong Nongye Daxue Xuehao* **13**(1): 46-50.

Yang, M.J., Lin, Q., Yang, J., Wei, F. and Zhang, M.Q. (2001). Study on the effect of sulphur fertilizer and nitrogen-sulphur balancing application of fertilizers to first cropping rice. *Fujian Agri. Sci. and Tech.* **1**: 2-3.

Yang, X., Yu, Y.G.,Yang, Y., Bell, R.W. and Te, Z.Q. (2000). Residual effectiveness of boron fertilizer rice based rotations nutrient cycling in Agro-ecosystems. **57**(2):71-78.

Yermiyahu, U., Keren, R. and Chen, Y. (2001). Effect of composted organicmatter on boron uptake by plants. *Soil Sci. Soc. of Americ. J.* **65**: 1436-1441.

Yu, Q., Baluska, F., Jasper, F., Menzel, D. and Goldbach, H.E. (2003). Short-term boron deprivation enhances levels of cytoskeletal proteins in maize, but not zucchini, root apices. *Physiol. Plant.* **117**: 270-278.

Zerrari, N., Moustaoui, D. and Verloo, M. (1999). The forms of boron in soil, effect of soil characteristics and availability for the plants. *Agrochimica.* **43**: 77-88.

Zhu, D., and Liu, W. (1999). Study on the properties of different chemical boron pools in soil, Investigation on plant availability of soil boron. *J. Huazhong Agric. university, Supplement.* **28**: 159-165.

APPENDICES

APPENDICES

Appendix I. Monthly records of Air temperature, Relative humidity and Rainfall of the experiment site during the period from July to November, 2011.

Month	* Air temperature (° C)		*Relative humidity (%)	*Rainfall (mm)
	Maximum	Minimum		
July	31.4	19.6	54	11
August	33.2	21.1	61	88
September	34.1	20.2	78	102
October	35.3	24.6	79	134
November	36.4	25.2	82	165

*Monthly Average

Source : Bangladesh Metrological Department (climate and weather division) Agargaon, Dhaka- 1212.

Appendix II. Analysis of variance of yield and yield attributes characters as influence by different levels of sulphur and boron

Source of variation	Degree of freedom	Mean sum of square								
		Plant height (cm)	Effective tillers $hill^{-1}$ (No.)	Non-effective tillers $hill^{-1}$ (No.)	Panicle length (cm)	Filled grains $panicle^{-1}$ (No.)	Unfilled grains $panicle^{-1}$ (No.)	Weight of 1000 grains (g)	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)
Replication	2	21.28 ^{NS}	1.10 *	0.136 ^{NS}	4.15 **	36.18 ^{NS}	2.07 ^{NS}	4.00 ^{NS}	0.999 **	0.783 ^{NS}
Sulphur(A)	3	14.00 ^{NS}	13.93 **	0.690 **	7.98 **	870.80 **	12.72 **	6.66 **	0.500 **	0.599 **
Boron (B)	3	47.71 *	5.20 **	0.362 **	2.73 *	13.63 *	0.222 ^{NS}	0.683 ^{NS}	1.199 **	2.688 **
AB	9	8.74 ^{NS}	1.28 **	0.056 ^{NS}	5.67 **	8.56 ^{NS}	0.850 *	0.430 ^{NS}	0.203 **	0.772 **
Error	30	6.20	9.97	1.029	0.741	4.72	0.337	0.667	0.039	0.074
Total	47	-	-	-	-	-	-	-	-	-

* → Significant at 5% level of probability

** → Significant at 1% level of probability

NS → Non significant

Appendix III. Analysis of variance of nutrient content as influence by different levels of sulphur and boron

Source of variation	Degree of freedom	Mean sum of square									
		N		P		K		S		B	
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Replication	2	0.002 NS	0.011 *	0.004**	0.083 **	0.021 **	0.301 *	0.001*	0.002**	1.712 *	0.077 *
Sulphur	3	0.123 *	0.171 *	0.222 *	0.021 **	0.388 **	0.021 *	0.008 *	0.003**	52.635**	12.709**
Boron	3	0.014 NS	0.012 *	0.0261 *	0.005 *	0.414 **	0.0541 *	0.008 *	0.001*	294.242**	215.649**
AB	9	0.006 NS	0.009 *	0.0579 *	0.573 *	0.686 *	0.003*	0.001 *	0.001 *	53.433**	10.833**
Error	30	0.005	0.012	0.0082	0.008	0.026	0.044	0.005	0.003	6.864	3.755
Total	47	-	-	-	-	-	-	-	-	-	-

* → Significant at 5% level of probability

** → Significant at 1% level of probability

NS → Non significant