EFFECT OF PHOSPHORUS AND SULPHUR ON THE GROWTH AND YIELD OF BRRI DHAN57

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CERTIFICATE

This is to certify that the thesis titled, **" Effect of Phosphorus and Sulphur on the growth and yield of BRRI Dhan 57"** submitted to the **Dept. of Soil Science Faculty of Agriculture, Sher–e–Bangla Agricultural University, Sher–e–Bangla Nagar, Dhaka** in partial fulfillment of the requirements for the degree of **Master Of Science (M.S.) in Soil Science** embodies the result of a piece of bona fide research work carried out by F. M. Shamim Ahmed; **Registration No. 06-02110** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

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DEDICATED TO

MY

BELOVED PARENTS

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ABSTRACT

An experiment was conducted at the Research Field of the Department of Soil Science, Sher-e-Bangla Agricultural University, Dhaka, during the period from July, 2013 to December, 2013 to study the performance of BRRI dhan57 regarding to growth, yield and yield contributing characters under the AEZ-28. The two factors experiment consists with four levels of Phosphorus (P) *viz.* P_0: without Phosphorus (control), P_1: 20 kg ha^{-1}, P_2: 40 kg ha^{-1} and P_3: 60 kg ha^{-1} and four levels of Sulphur *viz.* S_0: without Sulphur (control), S_1: 10 kg ha^{-1}, S_2: 20 kg ha^{-1} and S_3: 30 kg ha^{-1}. The experiment was laid out in Randomized Completely Block Design (RCBD) method with three replications and analysis was done by the MSTAT-C package program whereas means were adjusted by DMRT at 5% level of probability. It was found that all the traits were statistically significant due to Phosphorus whereas 40 kg P ha^{-1} recorded the tallest plant (109.70 cm) at harvest and maximum tillers $hill^{-1}$ (17.58) at 85 DAT. Phosphorus @ 40 kg ha^{-1} also recorded the greater results on effective tillers $hill^{-1}$ (13.67), panicle length (22.04 cm), filled grains $panicle^{-1}$ (138.60), 1000-grain weight (30.75 g), weight of grain, straw and biological (5.12, 8.39 and 13.51 t ha^{-1}, respectively) and harvest index (37.85%) at harvest while without phosphorus obtained the lower results on the above. In case of Sulphur, all the traits were significant except plant height at 55, 85 DAT and at harvest, filled grains $panicle^{-1}$ and 1000-grain weight whereas 20 kg S ha^{-1} obtained the tallest plant (109.40 cm) at harvest and maximum tillers $hill^{-1}$ (16.28) at 85 DAT. The maximum effective tillers $hill^{-1}$ (12.12), longest panicle (21.35), higher weight of grain, straw and biological (4.75, 8.08 and 12.82 t ha^{-1}, respectively) and harvest index (36.90%) were taken in 20 kg S ha^{-1} at harvest. It was also observed the minimum non effective tillers $hill^{-1}$ (2.83) and unfilled grains $panicle^{-1}$ (12.04) whereas all the Sulphur levels produced statistically similar filled grains $panicle^{-1}$ and 1000-grain weight at harvest due to non significant variation. All the studied characters were also significantly affected by the interaction effect between Phosphorus and Sulphur fertilizers whereas interactions affect between 40 kg P and 20 kg S ha^{-1} perform the best comparatively than that of other interactions. As a result, the tillers production had more at 85 DAT whereas the maximum tillers $hill^{-1}$ was 18.10. Plant height had also higher (111.60 cm) in 40 kg P + 20 kg S ha^{-1} at harvest. The interaction of 40 kg P + 20 kg S ha^{-1} also produced maximum effective (15.53) and minimum non effective tillers $hill^{-1}$ (1.97), longest panicle (23.26 cm), maximum filled (141.40) and minimum unfilled grains $panicle^{-1}$ (7.87), highest weight of 1000 grain (31.63 g), higher yield of grain, straw and biological (5.64, 8.97 and 14.60 t ha^{-1}) and higher HI (38.59%) whereas they were statistically significant among other interactions in respect of all the above traits. Nutrient content and uptake of N, P, K and S by grain and straw were also significantly affected by the singly or interaction effect of P and S in this study whereas the highest N, P, K and S nutrient content by grain (0.3540, 1.708, 0.3179 and 1.561%, respectively) and straw (0.1160, 0.8881, 0.0929 and 0.2894%, respectively) were recorded in 40 kg P ha^{-1} which was also showed the higher uptake by grain (16.82, 81.65, 15.27 and 75.63 kg ha^{-1}, respectively) and straw (9.74, 74.54, 7.80 and 24.29 kg ha^{-1}, respectively). Statistically similar observation was also obtained by 20 kg S ha^{-1} and 40 kg P × 20 kg S ha^{-1}. So, therefore, the present findings obviously recommended that 40 kg P ha^{-1} or 20 kg S ha^{-1} singly or their interactions would be optimum level for getting the higher production of BRRI dhan57.

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ABBREVIATIONS

%	=	Percentage
µM	=	Micro mol
^{0}C	=	Degree Celcius
AEZ	=	Agro–Ecological Zone
Agric.	=	Agriculture
Agril.	=	Agricultural
ANOVA	=	Analysis of variance
B	=	Boron
BARC	=	Bangladesh Agricultural Researcher Council
BARI	=	Bangladesh Agricultural Research Institute
BAU	=	Bangladesh Agricultural University
BBS	=	Bangladesh Bureau of Statistics
BRRI	=	Bangladesh Rice Research Institute
CRD	=	Completely randomized design
cv.	=	Cultivar
DAS	=	Days after sowing
DAT	=	Days after transplanting
DMRT	=	Duncan's Multiple Range Test
e.g.	=	Exempli gratia (by way of example)
EFSB	=	eggplant fruit and shoot borer
et al.	=	And others
FA	=	Foliar application
FAO	=	Food and Agriculture Organization
g	=	Gram
i.e.	=	edest (means That is)
IRRI	=	International Rice Research Institute
K	=	Potassium
LSD	=	Least significant difference
mgL^{-1}	=	Milligram per litre
P	=	Phosphorus
pH	=	Negative logarithm of hydrogen ion
RCBD	=	Randomized Complete Block Design
SA	=	Soil application
spp	=	Species (plural number)
UAE	=	United Arab Emirates
USDA	=	United stage of developmental agriculture
var.	=	Variety
Viz.	=	Namely
Zn	=	Zinc

Chapter I
Introduction

CHAPTER I
INTRODUCTION

Rice (*Oryza sativa* L.) is the dominant staple food for many countries in Asia and Pacific, South and North America as well as Africa (Mobasser *et al.*, 2007). It is also the most important food crop and a major food grain for more than a third of the world population (Zhao *et al.*, 2011). Rice is grown in more than a hundred countries with a total harvested area of nearly 160 million hectares, producing more than 700 million tonnes every year (IRRI, 2010). According to the Food and Agriculture Organization (FAO) of the UN, 80% of the world rice production comes from 7 countries (UAE/FAO, 2012). However, if we talk about world rice production 2009-2010, the worldwide rice production by countries- in fact, the top ten countries of world counted for their rice production raining is China: Mt: 166,417,000 (32.7%), India: Mt: 132,013,000 (26.0%), Indonesia: Mt: 52,078,832 (10.2%), Bangladesh: Mt: 38,060,000 (7.5%), Vietnam: Mt: 34,518,600 (6.8%), Thailand: Mt: 27,000,000 (5.3%), Myanmar: Mt: 24,640,000 (4.8%), Philippines: Mt: 14,031,000 (2.8%), Brazil: Mt: 10,198,900 (2.0%) and Japan: Mt: 9,740,000 (1.9%) (UAE/FAO, 2012).

In Bangladesh, during the year 2010–2011, rice covered an area of 28.5 thousand acres with a production of 33.5 million M tons while the average yield of rice in Bangladesh is around 1.2 thousand tons per acres whereas the transplant aman rice covers the largest area of 13951 acres (48.97%) with a production of 12792 thousand M tons rice grain (38.14%) and the average yield is about 971 kg ha^{-1} in Bangladesh in 2010–11 (BBS, 2012). Bangladesh is the 5^{th} largest country of the world in respect to rice cultivation (BBS, 2012). The population of Bangladesh is still growing and will require about 27.26 million tons of rice for the year 2020. But the average yield of rice is poor (4.34 t ha^{-1}) in Bangladesh (BRRI, 2011). On the other hand, rice production area is decreasing day by day due to high population pressure. Although, the average yield of rice is much lower as compared to other leading rice growing countries. Agriculture is the single largest producing sector of Bangladesh economy whereas the crop and horticulture sectoral GDP 429, 536 M Taka at 2012–13 whereas sectoral share of GDP at constant prices 10.25 with an average growth rate of 0.15 (BBS, 2012). Despite such a steady growth in agriculture as well as in food production, Bangladesh has been facing persistent challenges in achieving food security. This is mainly due to natural disasters and fluctuations in food prices (Rahman, 2011). About 75% of the total cropped area and more than 80% of the total irrigated area is planted to rice (Hossain and Deb, 2003). Almost all of the 13 million farm families grow rice in Bangladesh. It provides nearly 40% of national employment (48% of rural employment), about 70–76% of total calorie supply and 66% of protein intakes of an average person in the country (Anon., 2004a; Hossain and Deb, 2003). However, about 80% of the total lands are used for rice cultivation and it contributes 91.1% of the total grain production which covers 74% of the total calorie intake for the people of Bangladesh by the reports of MOA, 2001.

Bangladesh is a land of people and her population density is increasing day by day. To meet the demand of food for raising population the country needs to produce more rice. But the area availale for rice cultivation is limited. To increase prodcution, we need to emphasize on the use of balance fertilizers on both local and HYV rice. However, in Bangladesh, phosphorus and sulphur are used in soil enormously but nutrient stress in Bangladesh soils are increasing day by day. One of the major reasons for this is the use of imbalance fertilizers. Among the improved cultural practices, to insure proper growth, large amount of chemical fertilizers are applied in different crops field (Shakouri *et al*, 2012). Judicious and proper use of fertilizers can markedly increase the yield and improve the quality of rice (Alam *et al*, 2009). Fertilizer is very important input for intensive rice production. The profitability of rice production systems depends on yield and input quantities. So the appropriate fertilizer input that is not only for getting high grain yield but also for attaining maximum fertility (Khuang *et al*, 2008).

Phosphorus fertilizer is a major essential plant nutrient and key input for increasing crop yield (Dastan *et al*, 2012; Alinajoati Sisie & Mirshekari, 2011; Alam *et al*, 2009) and nutrient concentration of rice (Hossain *et al*., 2009; Fang *et al*., 2008; Fageria and Baligor, 2005). It palys a vital role in several physiological processes *viz* photosynthesis, respiration, energy storage and cell division/enlargement. It is also an important structural component of many biochemicals *viz* nucleic acid (DNA, RNA enzymes and co-enzymes) and also stimulates root growth and associated with early maturity of crops (Yosef, 2013a and b). It was also important for the phosphorus accumulation in cultivated soils is a concern for non-point environmental pollution and for efficiency of phosphorus resources becouse of excessive phosphorus input (Li *et al*., 2010). Phosphorus deficit is a most important restrictive factor in plant growth and recognition of mechanisms that increase plant phosphorus use efficiency is important (Alinajoati Sisie & Mirshekari, 2011). So, the appropriate fertilizer input that is not only for getting high grain yield but also for attaining maximum profitability (Khuang *et al*, 2008). It stimulates early root growth and development, encourages more active tillering, and promotes early flowering, maturity and good grain development (Khandaker, 2003). Manzoor *et al*., (2006) reported that the different varieties may have varying responses to P fertilizers depending on their agronomic traits. The application of phosphorous fertilizer either in excess or less than optimum rate affects both yield and quality to a remarkable extent. Similarly, P is a major component in ATP, the molecule that provides "energy" to that plant for such processes as photosynthesis, protein synthesis, nutrient translocation, nutrient uptake and respiration. Phosphorus is also a component of other compounds necessary for protein synthesis and transfer of genetic material DNA and RNA. Phosphorus application to rice increased P accumulation but did not consistently increase rice yields because flooding decreased soil P sorption and increased P diffusion.

Sulphur (S) is another essential macronutrient and it plays a vital role in the plant system and its deficiency in Bangladesh was first detected in rice at BRRI farm at Joydebpur in 1976. In recent years, S deficiency has been receiving much attention as a major limiting factor for wetland rice. For rice cultivation, next to nitrogen, S application is very important. So, in fertilizer schedule, it is commonly included (Islam *et al.*, 2009). Sulphur deficiency affects not only the growth and yield of rice but also the protein quality through its effect on the synthesis of certain amino acids such as cystein and methionine. The use of almost sulphur free fertilizer such as Urea and triple super phosphate (TSP) may be an important reason for widespread occurrence of Sulphur deficiency problem. So, it is needed to pay more attention to conduct more research with appropriate dose of S fertilizer in rice.

From the above aspects, it is appeared that the cultivation of rice is the most effective means to increase the yield per unit area by applying the proper doses of P and S fertilizers. Considering above points, the present study was undertaken to achieve the following objectives:

- to examine the differences of morpho–physilogy and grain production of BRRI dhan57 as influence by the various doses of P and S
- to find out the appropriate doses of P and S regarding to proper growth and higher production of BRRI dhan57
- to select the most advantigious treatment combination of P and S fertilizers concerning to growth and yield of BRRI dhan57.

Chapter II
Review of literature

CHAPTER II
REVIEW OF LITERATURE

An attempt has been made in this chapter to present a brief and relevant review of many researchers in relation to the effects of P and S on the growth and yield of BRRI dhan57 in Bangladesh perspective and also in the other parts of the world. The related review of literature was present under the following heading and sub headings:

2.1 Effect of phosphorus (P) on growth and yield characters of rice

A field experiment was conducted by Srivastava *et al.* (2014) on basmati rice–wheat rotation with combinations of Zn levels (0, soil application of 2.5 kg Zn ha^{-1} and two foliar applications of 2.0 kg Zn ha^{-1}) and P levels (0, soil application of 8.7, 17.5 and 26.2 kg P ha^{-1}). The highest pooled grain yields of basmati rice and wheat were obtained with soil application of 17.5 kg P ha^{-1} and foliar applications of 2 kg Zn ha^{-1}.

In order to investigate the effect of nitrogen and phosphorus fertilizer on spikelet Structure and yield in rice (*Oryza sativa*), an experimental design in north of Iran in 2011 cropping season (Yosef, 2013b). Nitrogen fertilizer at 50,100 and 150 kg ha^{-1} was main plot and phosphorus fertilizer at 4 level 0 (control), 30, 60 and 90 kg ha^{-1} as sub plot. Using randomized complete block desing (RCBD) with 3 replications. The effect of phosphorus fertilizer on spikelet number and yield was significant in 1% probability level. Fertile spikelet, fertile spikelet percentage (%), sterile spikelet percentage (%) and biological yield were significant in 5% probability level. Spikelet number under phosphorus fertilizer treatment in P_1 to P_4 was (89.63), (90.54), (96.67) and (97.41), respectively. Increasing the levels of P up to 26.4 kg ha^{-1} also significantly increased ($p<0.01$), the number of spikelets $panicle^{-1}$. Application of P increases the total number of spikelets $panicle^{-1}$ in rice thereby contributing to increment in grain yield (Gebrekidan and Seyoum, 2006).

Fertile spikelet percentage (%) under phosphorus fertilizer treatment in P_1 to P_4 was (76.29), (77.80), (83.08) and (82.04), respectively. Maximum Spikelet sterility percentage (%) was (23.71) observed for (control) 0 kg ha^{-1} phosphorus fertilizer and minimum of that was (16.36) obtained for 60 kg ha^{-1} phosphorus fertilizer. Maximum grain and biological yield was (4470) and (9120), respectively that observed for 90 kg ha^{-1} phosphorus fertilizer and minimum of these was (3650) and (7638), respectively obtained for (control) 0 kg ha^{-1} phosphorus fertilizer. Maximum harvest index was (47.92) observed for 90 kg ha^{-1} phosphorus fertilizer and minimum of that was (47.79) obtained for (control) 0 kg ha^{-1} phosphorus fertilizer. Application of 13.2 kg P ha^{-1} significantly ($p<0.01$) increased harvest index of rice, accordingly harvest index of the rice crop was negatively and significantly correlated with planet height, panicle length, number of panicle m^{-2}, number of spikelets $panicle^{-1}$ and staw yield.

An experiment was conducted by Yosef (2013a) to investigate the effect of nitrogen and phosphorus fertilizer on growth and yield in rice cultivar Tarom Hashemi, an experimental design in north of Iran in 2011 cropping season. Nitrogen fertilizer at 50,100 and 150 kg ha^{-1} was main plot and phosphorus fertilizer at 4 level 0 (control), 30, 60 and 90 kg ha^{-1} as sub plot. Using randomized complete block desing (RCBD) with 3 replication. The phosphorus fertilizer on plant height, stem height, total tiller no significant effect, nevertheless, the maximum total tiller, plant and stem height was 26.8 tiller, 158.3 and 129 cm, respectively that obtained from the treatment of P_3 (60 kg ha^{-1}) and P_4 (90 kg ha^{-1} P fertilizer) probability. The lowest of these was found from (control) 0 kg ha^{-1} P fertilizer. Tiller production was also highly responsive to phosphorus levels. Maximum fertile tiller percentage (%) was (79.54) observed for 90 kg ha^{-1} phosphorus fertilizer and minimum of that was (66.73) obtained for (control) 0 kg ha^{-1} phosphorus fertilizer. Maximum barrier tiller was (8.15) observed for (control) 0 kg ha^{-1} P fertilizer and minimum of that was (5.36) obtained for 90 kg ha^{-1} phosphorus fertilizer. Barrier tiller percentage (%) under phosphorus fertilizer treatment in P_1 to P_4 was (33.27), (28.72), (25.45) and (20.46) respectively. The effective tillers hill^{-1} of rice verities also varied significantly due to P fertilizer application, plant grown without P fertilizer had the lowest effective tillers hill^{-1}, rice plants to accelerate the phosphate absorption for increased tillering. Maximum grain yield was (4540) observed for 90 kg ha^{-1} phosphorus fertilizer and minimum of that was (3800) obtained for (control) 0 kg ha^{-1} phosphorus fertilizer.

Field experiments were conducted to study the interaction of phosphorus, sulfur and zinc on growth and yield of rice in neutral and alkali soils by Rasavel and Ravichandran (2013). The treatments consisted of two levels of P_2O_5 (25, 50 kg ha^{-1}), two levels of S (20, 40 kg ha^{-1}) and four levels of Zn (0, 5, 10, 15 kg ha^{-1}) besides an absolute control, thus totaling seventeen treatments. The highest plant height (89.5, 52.8 cm), number of tillers hill^{-1} (17.2, 16.3), LAI (5.89, 5.12), chlorophyll content (4.58, 4.16 mg g^{-1}), DMP (8436, 7385 kg ha^{-1}), panicle length (24.9, 21.6 cm) and number of grain panicle^{-1} (115.6, 108.3) was noticed with application of 50 kg P_2O_5 ha^{-1}, 20 kg S ha^{-1} and 10 kg Zn ha^{-1} (T_8) in neutral and alkali soils respectively. It was superior to rest of the treatment combinations except T_{16} (50 kg P_2O_5 ha^{-1}, 40 kg S ha^{-1} and 10 kg Zn ha^{-1}). The growth was reduced at the highest level of P, S and Zn applied. The highest grain (5216, 4678 kg ha^{-1}) and straw yields (6123, 5642 kg ha^{-1}) was noticed with application of 50 kg P_2O_5, 20 kg S and 10 kg Zn ha^{-1} in neutral and alkali soils respectively. This was comparable with 50 kg P_2O_5, 40 kg S and 10 kg Zn ha^{-1}. For given level of phosphorus and sulfur, increasing levels of zinc improved the grain yield by 2.5 to 15.3 per cent. However, when all the three nutrients were applied at highest level, yield reduction was noticed. Increasing phosphorus doses significantly increased the yield attributes and yield over control. The rate of increase in grain yield with each successive increment in P dose was more than that in straw yield.

Yosef (2012) studied to investigate the effect of nitrogen and phosphorus fertilizer on growth and yield in rice cultivar Tarom Hashemi, an experimental design in north of Iran in 2011 cropping season. Nitrogen fertilizer at 50,100 and 150 kg ha^{-1} was main plot and phosphorus fertilizer at 4 level 0 (control), 30, 60 and 90 kg ha^{-1} as sub plot. Using randomized complete block design (RCBD) with 3 replications. The results showed that tiller number, fertile tiller, total grain, 1000-grain weight and yield increased significantly with nitrogen and phosphorus fertilizer. Interesting in comparison to 50 and 100 kg ha^{-1} level application of higher N-fertilizer 150 kg ha^{-1} showed a positive respond to application of high nitrogen for Taroom Hashemi cultivar. Effect of different application of P-fertilizer was significantly on this parameter, increase application of phosphorus increase parameter above. Study of interaction effect of N and P- fertilizer was significant in fertile tiller and 1000-grain weight.

The present study was carried out by Dinesh *et al.* (2012) at Research Farm of College of Agriculture, Kaul (Kaithal) Chaudhary Charan Singh Haryana Agricultural University, Hisar during kharif season of 2010 on clay loam alkaline soil, low in organic carbon and available nitrogen, medium in phosphorus and high in potassium. The treatments consisted of four cultivars (CSR-30, HKR03-408, Pusa Basmati-1 and Pusa Basmati-1121) and six NP levels laid out in split-plot design with three replications, keeping cultivars in main plots and NP levels in sub plots. Increasing NP levels significantly increased all the crop growth parameters *viz.* plant height, tillers m^{-2}, dry matter accumulation. The yield contributing characters (panicles m^{-2}, grains $panicle^{-1}$), yield (grain and straw), net profit and benefit cost ratio were higher with $N_{90}P_{45}$ kg ha^{-1}.

Growth and yield attributes of rice were evaluated by Bakhsh *et al.* (2012) with the application of varying doses of Naphthalene Acetic Acid (NAA) and Phosphorus during 2004 and 2005. The experiment was laid out in Randomized Complete Block (RCB) Design with split-plot arrangements and replicated four times. Main plots were assigned to four levels (0, 60, 90 and 120 ml ha^{-1}) of NAA. Results revealed that phosphorus application up to 100 kg ha^{-1} boosted up the rice productivity due to maximum value recorded in terms of panicles m^{-2} (347.5 and 349.5), spikelets $panicle^{-1}$ (153.3 and 153.8), sterility (22.25 and 19.94 %), normal kernel (77.25 and 78.69 %), paddy yield (7.62 and 7.82 t ha^{-1}) and net income (Rs. 30986 and 32236 ha^{-1}) with BCR of 1.64 and 1.70 indicating the economical yield of rice during 2004 and 2005, respectively.

Field experiments were conducted to examine the effects of water management (WM) and Phosphorus (P) rates on as uptake and yields in rice by Talukder *et al.* (2010). There were 6 treatments consisting of two tillage options [Permanent raised bed-PRB (aerobic WM) and conventional till on flat-CTF (anaerobic WM)] and three P levels (0%, 100% and 200% of recommended P) using two rice varieties, in an As-contaminated field at Gaibandha, Bangladesh in 2004 and 2005. Significantly, the highest grain yields (6.65 and 7.12 t/ha in winter season irrigated rice (*boro)* 6.36 and 6.40 t ha^{-1} in monsoon rice (*aman)* in both the years' trials) were recorded in PRB (aerobic WM: Eh = +360 mV) plus 100% P amendment. There was a 14% yield increase over CTF (anaerobic WM: Eh = -56 mV) at same P level.

A field experiment was carried out by Alam *et al.* (2009) at the Agronomy Field of the Sher-e-Bangla Agricultural University, Dhaka during December 2006 to June 2007 to study the relative performance of inbred and hybrid rice varieties at different levels of phosphorus (P). Three varieties of inbred and hybrid rice and five levels of P (0, 24, 48, 72 and 96 kg P_2O_5 ha^{-1}) were used as treatment. Number of tillers $hill^{-1}$, filled grains $panicle^{-1}$, unfilled grains $panicle^{-1}$, spikelet sterility, 1000-grain weight, grain yield and straw yield differed significantly with the application of P fertilizer while harvest index did not vary significant. Phosphorus at 72 kg ha^{-1} (P_3) produced the highest grain yield (7.23 t ha^{-1}) ofrice. Plants grown without added P gave the lowest grain yield (4.99 t ha^{-1}).

Iqbal (2004) carried out an experiment on interactions of N, P and water application and their combined effects on biomass and yield of rice. It was concluded that the yield of rice increased by 50-60% in response to the application of N and P interaction with H_2O. An experiment was conducted by Khandaker (2003) at the BRRI, Gaizpur during boro season to determine the optimum rate and effect of different time of P application on the growth and yield of rice. Phosphorus application enhances all the growth parameters and increased the grain and straw yields. Application of P @ 30, 45, 60 and 75 kg ha^{-1} exerted more or less similar effects on growth parameters. Phosphorus application @ 30 kg ha^{-1} produces statistically similar grain and straw yields as well as the total yield compared to those with 45, 60 and 75 kg ha^{-1}, respectively but superior to the plants treated with P @ 15 kg ha^{-1} and the control.

Salton *et al.* (2002) studied the response of rice to phosphorus application rate and time in six commercial rice fields. Three rates of P (9.8, 19.6 and 39.1 kg p ha^{-1}) were applied at four different times during the growing season including pre-emergence (PRE), pre-flood (PF), 5 to 10 d post flood (POF) or at mid season (MS) and compared with an untreated control. Significant grain yield increases were measured at two of the six locations. They observed that grain yields were maximized by application of 19.6 kg P ha^{-1} at the two highly responsive sites with yield increases of 20 to 41%.

Tripathi *et al.* (2001) conducted a pot experiment to study the effects of various levels of P on the grain and straw yields. They concluded that increasing levels of P significantly enhanced the yield.

Kumar and Singh (2001) reported that the significantly response of rice to P was observed only up to 26.2 kg P ha^{-1} and application of P in all seasons recorded maximum rice equivalent yield (79.6 q ha^{-1}) which was at par with treatment receiving P in both year rabi (70.8 q ha^{-1}) and treatment receiving P in first year kharif and rabi (70.8 q ha^{-1}).

2.2 Main effects of Sulphur (S) on growth and yield of rice

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

Field experiments were conducted to study the interaction of phosphorus, sulfur and zinc on growth and yield of rice in neutral and alkali soils (Rasavel and Ravichandran, 2012). The treatments consisted of two levels of P_2O_5 (25, 50 kg ha^{-1}), two levels of S (20, 40 kg ha^{-1}) and four levels of Zn (0, 5, 10 and 15 kg ha^{-1}) besides an absolute control, thus totaling seventeen treatments. The results revealed significant interactions among P, S and Zn on growth and yield of rice. The highest plant height (52.8 cm), number of tillers $hill^{-1}$(16.3), LAI (5.12), panicle length (21.6 cm) and number of grain $panicle^{-1}$ (108.3) was noticed with application of 20 kg S ha^{-1} + 10 kg Zn ha^{-1} (T_8) in alkali soils respectively. The highest grain (4678 kg ha^{-1}) and straw yields (5642 kg ha^{-1}) was noticed with application of 20 kg S + 10 kg Zn ha^{-1} in alkali soils.

Devi *et al.* (2012) studied the effect of sulphur and boron fertilization on yield, quality and nutrient uptake by soybean under upland condition. The experiment comprises five levels of sulphur (0, 10, 20, 30 and 40 kg sulphur per hectare) and five levels of boron (0, 0.5, 1.0, 1.5 and 2.0 kg boron per hectare). The study revealed that yield attributing characters like number of branches per plant, pods per plant and 100 seed weight and yield were increased with the application of sulphur and boron as compare to control. The overall result revealed that application of 30 kg sulphur per hectare and 1.5 kg boron per hectare were found to be the optimum levels of sulphur and boron for obtaining maximum yield attributes, yield, oil and protein content, total uptake of sulphur and boron, net return, cost and benefit ratio of soybean under upland condition as compare to other levels of sulphur and boron respectively.

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

Bhuiyan *et al.* (2011) investigated the kharif-II season of 2002 at the Bangladesh Agricultural University Farm, Mymensingh, to find out the integrated use of organic and inorganic fertilizers on the yield of T. Aus and mungbean in a Wheat-T. Aus/mungbean-T. Aman cropping sequence. The rates of N, P, K and S for T. Aus rice were 60, 12, 32 and 5 kg ha^{-1} for MYG, and 90, 18, 48 and 7.5 kg ha^{-1} for HYG, respectively. The variety BR 26 for T. Aus rice was planted in all three years. The results showed that grain yields (3.46 t ha^{-1}) and straw yields

(5.19 t ha^{-1}) of T. Aus rice (mean of three years) was increased significantly by the application of fertilizers. The application of chemical fertilizers, NPKS (HYG) remarkably increased the crop yields while the lowest mean grain yields of 1.48 t ha^{-1} for T. Aus and 0.42 t ha^{-1} for mungbean were recorded in the unfertilized control plots.

Field experiment was conducted by Jawahar and Vaiyapuri (2010) at Experimental Farm, Annamalai University, Annamalai Nagar, Tamil Nadu, India during 2007-2008 to study the effect of sulphur and silicon fertilization on yield, nutrient uptake and economics of rice. The treatments comprised four levels of sulphur (0, 15, 30 and 45 kg ha^{-1}) and silicon (0, 40, 80 and 120 kg ha^{-1}) and were laid out in factorial randomized block design with three replications. Among the different levels of sulphur, application of 45 kg S ha^{-1} recorded maximum grain and straw yield of rice, which was closely followed by 30 kg S ha^{-1}. This treatment recorded 18.12, 7.47 and 2.43 per cent increase over 0, 15 and 30 kg S ha^{-1}. Higher grain and straw yield due to S may be attributed to increase in growth and yield characters of rice and to be stimulating effect of applied S in the synthesis of chloroplast protein resulting in greater photosynthetic efficiency, which in turn increased the yield

Rahman *et al*. (2009) studied to know the effect of different levels of Sulphur on growth and yield of BRRI dhan 41 at Soil Science Field Laboratory of Bangladesh Agricultural University (BAU), Mymensingh during T. aman season of 2007. There were eight treatments with three replications. Recommended dose were of fertilizer N 90 kg ha^{-1}, P 15 kg ha^{-1}, K 40 kg ha^{-1} and Zn 2 kg ha^{-1} were applied as basal does from urea, TSP, Muriate of Potash and Zinc Oxide, respectively and S at 90 kg ha^{-1} from gypsum was applied as per treatments by BARC, 2005. The treatments used in the experiment were T_0 (without S), T_1 (50% RFD of S), T_2 (75% RED of S), T_3 (100% RFD of S), T_4 (125% RFD of S), T_5 (150% RFD of S), T_6 (175% RFD of S) and T_7 (200%

RFD of S). All yield contributing characters like effective tillers $hill^{-1}$ filled grain $panicle^{-1}$, grain yield, straw yield, biological yield and 1000-grain weight except plant height and panicle length of BRRI dhan 41 significantly responded to different levels of applied S.

Islam *et al.* (2009) conducted an experiment at the Department of Soil Science of Bangladesh Agricultural University (BAU), Mymensingh during T. aman season of 2006 to evaluate the effects of different rates and sources of sulphur on the yield, yield components, nutrient content and nutrient uptake of rice (cv. BRRI dhan30). There were seven treatments consisting of four levels of sulphur (0, 8, 12 and 16 kg S ha^{-1}) applied. The grain and straw yields as well as the other yield contributing characters like effective tillers $hill^{-1}$, panicle length, filled grains $panicle^{-1}$ and 1000 grain weight were significantly influenced due to application of sulphur. The highest grain yield of 5293 kg ha^{-1} and straw yield of 6380 kg ha^{-1} were obtained from 16 kg S ha^{-1} applied as gypsum. The lowest grain yield (4200 kg ha^{-1}) and straw yield (4963 kg ha^{-1}) were recorded with S control treatment. The overall results suggest that application of sulphur @ 16 kg S ha^{-1} as gypsum was the best treatment for obtaining higher grain yield as well as straw yield of T. aman rice.

Rahman *et al.* (2007) conducted a field experiment on a non-calcareous dark gray floodplain soil (Sonatola series) of BAU farm, Mymensingh during Boro season of 2004 using rice (cv. BRRI dhan29) as a test crop. The soil was silt loam having pH 6.8, organic matter 1.62%, available Sulphur (S) 9 ppm and available Phosphorus (P) 7.62 ppm. All plots received an equal dose of N, P, K and Zn. The application of S had a significant positive effect on tillers $hill^{-1}$, plant height, panicle length and grains $panicle^{-1}$. The highest grain (5.81 t ha^{-1}), and straw (7.38 t ha^{-1}) yields were recorded in 20 kg S ha^{-1}. The control had the lowest grain yield of 4.38 t ha^{-1} as well as the lowest straw yield of 5.43 t ha^{-1}.

Regression analysis showed that the optimum dose of S was 32.89 kg ha^{-1} and the economic dose of S was 31.59 $kgha^{-1}$ for maximizing the yield.

Lar Oo *et al.* (2007) studied on the effect of N and S levels on productivity and nutrient uptake in aromatic rice. The experiment was carried out with 16 treatments combinations of 4 N levels (0, 50, 100 and 150 kg ha^{-1}) and 4 S levels (0, 20, 40 and 60 kg ha^{-1}) 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^{-1} over control was 1.99 tonnes ha^{-1} and 1.95 tonnes 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.

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

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

Raju and Reddy (2001) conducted field investigations at Agricultural Research Station, Maniteru, Andhra Pradesh, India to study the response of both hybrid and conventional rice to Sulphur (at 20 kg ha^{-1}) and Zinc (at 10 kg ha^{-1}) applications. Conventional rice, MTU 2067 out yielded the hybrid rice MUT-

HR 2003 by 21%. Significant improvement in grain yield was observed due to sulphur application. Zinc application failed to improve the yield markedly.

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

Li and Li (1999) conducted pot experiments with rice grown on black soils given NPK (control), NPK+Ca, NPK+gypsum, NPK+S or NPK +Ammonium Sulphate. Application of ammonium sulphate or elemental S increased yield by 28.8% and 19.7% respectively. In the field experiment S increased yield by 9.71%. The added element increased plant growth, the number of tillers, grains/ panicle and yield.

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

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

Uddin *et al.* (1997) conducted a field experiment in Patuakali during aman season of 1990 to see the effect of N, P, and S on the yield of rice cv. Haloi.

They reported that application of 20 kg S ha^{-1} increased tillering, grains panicle^{-1} and grain yield of rice.

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

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

Islam *et al.* (1996) conducted field experiments during T. aman season of 1992 to examine the response of BR 11 rice to S, Zn and B. They found that application of 20 kg S ha^{-1} at both locations significantly increased the grain yield of rice.

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

Islam *et al.* (1995) carried out a field experiment during aman season of 1992 to investigate the response of BR 31 rice to different nutrients including S. They reported that application of 20 kg S ha^{-1} with 100 kg N ha^{-1} increased the grain yield by 1300 kg N ha^{-1} application. Mukhopadhyay *et al.* (1995) found that gypsum and pyrite were equally effective in increasing rice yield when applied at the rate of 20 kg S ha^{-1}.

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

Chapter III

Materials and Methods

CHAPTER III
MATERIALS AND METHODS

This chapter describes the experimental aspects of the study. The experiment was conducted at the research farm of the Department of Soil Science (plot no. 20), Sher-e-Bangla Agricultural University (SAU), Sher-e-Bnagla Nagar, Dhaka–1207 during the period from July 2013 to December 2013 (Kharif II) to study the most appropriate singl or combined doses of Phosphorus (P) and Sulphur (S) on the aspect of better growth, higher production and yield and quality of grain and straw of studied rice cultivar cv. BRRI dhan57. This section for convenience of presentation has been divided into various sub–sections such as site and soil, climatic condition, experimental materials, land preparation, experimental design, treatments, fertilizer application, sowing and transplanting, intercultural operations, harvesting and threshing, data collection, soil analysis and statistical analyses.

3.1 Site Description

3.1.1 Geographical Location

Geographically, the experimental area is located at $23^0 41'$ N latitude and $90^0 22'$ E longitudes. The area lies at 8.6 meter above mean sea level (Anon., 2004b).

3.1.2 Agro–Ecological Region

The experimental field belongs to the Agro-ecological zone of "The Modhupur Tract", AEZ-28 (Anon., 1988a). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hillocks of red soils as 'islands' surrounded by floodplain (Anon., 1988b).

3.1.3 Soil

The soil of the experimental site belongs to the general soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. Top soils were clay loam in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.8 and had organic matter 1.3%. The experimental area was flat having available irrigation and drainage system and above flood level. Soil samples from 0-15 cm depths were collected from experimental field. Soil samples were analyzed for both physical and chemical properties in the laboratory of the SRDI, Farmgate, Dhaka. The properties studied included pH, organic matter, total N, available P and exchangeable K. The soil was analyzed following standard methods. Particle-size analysis of soil was done by Hydrometer method and soil pH was measured with the help of a glass electrode pH meter using soil water suspension of 1:2.5. The physico-chemical properties of the soil are presented in Appendix I.

3.1.4 Climate and weather

The experimental area is situated in the sub-tropical climatic zone and characterized by heavy rainfall during the months of April to September (Kharif Season) and scanty rainfall during the rest period of the year (Biswas, 1987). The Rabi season (October to March) is characterized by comparatively low temperature and plenty of sunshine from November to February (SRDI, 1991). The detailed meteorological data in respect of air temperature, relative humidity, total rainfall and soil temperature recorded by the National Meteorological Research Centre, Dhaka during the period of study have been presented in Appendix II.

3.2 Details of the Experiment

3.2.1 Plant materials (variety)

The seeds of BRRI dhan57 were used as planting materials which was collected from the Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur–1701.

3.2.2 Experimental treatments

Different doses of Phosphorus (P) and Sulphur (S) were applied in experimental field as experimental treatments where K and P were used as factor A and B, respectively. From the above experimental treatments it will be mentioned as are as follows

Factor A: Four doses of Phosphorous (P)

P_0 : 0 kg P ha^{-1} (control)

P_1 : 20 kg P ha^{-1}

P_2 : 40 kg P ha^{-1}

P_3 : 60 kg P ha^{-1}

Factor B: Four doses of Sulphur (S)

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

S_1 : 10 kg S ha^{-1}

S_2 : 20 kg S ha^{-1}

S_3 : 30 kg S ha^{-1}

So, the treatments combinations were as follows

P_0S_0 : 0 kg P ha^{-1} × 0 kg S ha^{-1} (control)

P_0S_1 : 0 kg P ha^{-1} × 10 kg S ha^{-1}

P_0S_2 : 0 kg P ha^{-1} × 20 kg S ha^{-1}

P_0S_3 : 0 kg P ha^{-1} × 30 kg S ha^{-1}

P_1S_0 : 20 kg P ha^{-1} × 0 kg S ha^{-1}

P_1S_1 : 20 kg P ha^{-1} × 10 kg S ha^{-1}

P_1S_2 : 20 kg P ha^{-1} × 20 kg S ha^{-1}

P_1S_3 : 20 kg P ha^{-1} × 30 kg S ha^{-1}

P_2S_0 : 40 kg P ha^{-1} × 0 kg S ha^{-1}

P_2S_1 : 40 kg P ha^{-1} × 10 kg S ha^{-1}

P_2S_2 : 40 kg P ha^{-1} × 20 kg S ha^{-1}

P_2S_3 : 40 kg P ha^{-1} × 30 kg S ha^{-1}

P_3S_0 : 60 kg P ha^{-1} × 0 kg S ha^{-1}

P_3S_1 : 60 kg P ha^{-1} × 10 kg S ha^{-1}

P_3S_2 : 60 kg P ha^{-1} × 20 kg S ha^{-1}

P_3S_3 : 60 kg P ha^{-1} × 30 kg S ha^{-1}

3.3 Experimental design and layout

The experiment consisted of four doses of P and four doses of S and was laid out a two factors split-plot (Phosphorus in the main plot and Sulphur in the sub-plot) in Randomized Complete Block Design (RCBD) with three replications. The size of plot was 4.0 × 3.0 m (12 m^2) where block to block and plot to plot distance was 0.75m and 0.5 m, respectively. Row to row and plant to plant distance were also 20cm and 20 cm, respectively, in each plot. So, the total plots were 48 (P 4 × K 4 × Replication 3). The layout of the experiment was presented in Appendix III.

3.4 Crop Management

3.4.1 Seed collection

Seeds of BRRI dhan57 were collected from Genetic Resource and Seed Division, BRRI, Joydebpur, Gazipur, Bangladesh.

3.4.2 Seed sprouting

Seeds were selected by following specific gravity method. Seeds were immersed into water in a bucket for 24 hours. These were then taken out of water and kept tightly in gunny bags. The seeds started sprouting after 48 hours which were suitable for sowing in 72 hours.

3.4.3 Preparation of seedling nursery

A common procedure was followed in raising seedlings in the seedbed. The seedbed was prepared by puddling with repeated ploughing followed by laddering. Weeds were removed and irrigation was gently provided to the bed as and when necessary. No fertilizer was used in the nursery bed. For SRI, sprouted seeds were sown as broadcast in two portable trays containing soil and cowdung. Thin plastic sheets were placed at the base of the trays to protect water loss. The moisture of the trays was controlled accurately by applying water everyday, which ensured proper growth of all the seedlings in the trays. These trays were kept inside a room at night to protect the seedlings from freezing temperature of the season and kept in sunlight at daytime for proper development of seedlings.

3.4.4 Seed Sowing

Seeds were sown in the nursery seed bed on 9 July, 2013.

3.5 Land preparation for transplanting

The experimental field was opened on 29 July, 2013 and prepared by ploughing and cross ploughing with power tiller and country plough. Then the land was laddered with traditional tools. Thereafter, the land was ploughed and cross–ploughed and deep ploughing was obtained good tilth, which was necessary to get better yield of this crop. Laddering was done in order to break the soil clods into small pieces followed by each ploughing. All the weeds and stubbles were removed from the experimental field. The plots were spaded one day before planting and the whole amount of fertilizers were incorporated thoroughly before planting according to Fertilizer Recommendation Guide (BARC, 2005). After uniform leveling, the experimental plots were laid out according to the requirement of the design.

3.6 Fertilizer application

Phosphorus and Sulphur fertilizers were applied to each plot as per treatments. Fertilizer such as Urea, TSP, MoP, Gypsum and $ZnSO_4$ were used as source for N, P, K, S, and Zn, respectively. Phosphorus and Sulphur required for each unit plot were calculated from the rate of application as per treatments. Among the other fertilizer, one-third of urea and the entire required amounts of other fertilizers were applied as basal to the individual plots during final land preparation (BRRI, 2011). The fertilizers were incorporated into soil by spading. The second split of urea was applied at maximum tillering stage and the remaining split at panicle initiations stage. The rates and sources of different nutrients used in this experiment are given as below

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

Nutrient element	Source	Rate(Kg ha^{-1})
Sulphur	Gypsum (18% S)	0, 10, 20 and 30
Zinc	ZnSO4	80
Nitrogen	Urea (46% N)	120
Phosphorus	TSP (20% P)	0, 20, 40 and 60
Potassium	MoP (50% K)	80

Source: BRRI 2011 (Fertilizer Recommended Guide)

3.7 Uprooting of seedlings

The seedbeds were made wet by application of water on the previous day before uprooting the seedlings. The seedlings were uprooted carefully without causing dry injury to the roots. The uprooted seedlings were kept on soft mud under shade.

3.8 Transplanting of seedlings

On 11th August 2013, 32 day old seedlings were transplanted in the experiment field keeping plant to plant distance 20 cm and row to row distance 20 cm. Gap filling was made up to 7 days after transplanting to maintain proper treatment and similar plant population density for every plot.

3.9 Intercultural operations

After transplanting of the seedlings, different operations as and when necessary were carried out for better growth and development of the plant.

3.9.1 Weeding

Few weeds namely, durba, shama, chesra, maluncha and mutha were found in each plot after two weeks of transplanting. They were uprooted immediately by hand pulling.

3.10 Sampling and data collection

Sampling was done during harvest. At each sampling five random hills from each plot were uprooted avoiding border hills and washed them in running tap water. Then the plant samples were carried to the laboratory and plant height and number of tiller were recorded.

3.11 Harvest and post harvest operations

Harvesting was done when 80–90% of the grains became golden in color. Five hills excluding border hills were randomly selected from each plot. Selected plants were cut at the ground level and were separately bundled and properly tagged for recording necessary data. Grain and straw yields were determined by harvesting the whole plot leave border and sampling area. The harvested crops were then threshed and cleaned. Grain and straw weights were recorded after proper sun drying. The harvested seeds of this experiment were stored in plastic airtight container for further investigation of seed qualitative parameters.

3.12 Parameters studied

Growth, yield and yield contributing characters

- (i) Plant height (cm)
- (ii) Number of total tillers hill^{-1}
- (iii) Number of effective tillers hill^{-1}
- (iv) Number of non effective tillers hill^{-1}
- (v) Number of filled grains panicle^{-1}
- (vi) Number of unfilled grains panicle^{-1}
- (vii) 1000 grain weight (g)
- (viii) Grain yield (t ha^{-1})
- (ix) Straw yield (t ha^{-1})
- (x) Biological yield (t ha^{-1})
- (xi) Harvest index (%)

3.13 Measurement of yield and yield contributing characters

3.13.1 Plant height (cm)

The effective plant height was considered from ground level to the tip of the leaf at vegetative phase and panicle at harvest stage. Plant height data was measured by a meter scale and converted into cm and recorded at 30 days interval from 25 DAT (days after transplanting) up to 85 DAT (days after transplanting) and at harvest.

3.13.2 Number of total tillers hill^{-1}

Number of tillers hill^{-1} were recorded at 25, 55, 85 DAT and at harvest from the randomly selected 5 hills where all the effective tillers and non effective tillers were considered for counting the total tillers at every data recording stages.

3.13.3 Number of effective tillers hill^{-1}

The panicles which had at least one grain was considered as effective tiller. The number of effective tillers of 5 hills was recorded and expressed as effective tillers number hill^{-1} at harvest.

3.13.4 Number of non–effective tillers hill^{-1}

The tiller having no panicle was regarded as non-effective tiller. The number of ineffective tillers 5 hills^{-1} was recorded and was expressed as non–effective tiller number hill^{-1} at harvest.

3.13.5 Length of panicle (cm)

Panicle length was measured by a meter scale from the basal node of the rachis to the apex of each panicle from the randomly selected 5 hills and their average was recorded and converted in cm.

3.13.6 Number of filled grains panicle^{-1}

Filled grain was considered to be filled if any kernel was present there in. Number of filled grain was recorded from randomly selected 5 hills and converted into filled grains panicle^{-1}.

3.13.7 Number of unfilled grain panicle^{-1}

Number of unfilled grains panicle^{-1} means the absence of any kernel inside in and such grains present on each hill were counted from the randomly selected 5 hill.

3.13.8 Thousand grain weight (g)

One thousand cleaned dried seeds were counted randomly from each sample and weighed by using a digital electric balance at the stage the grain retained 12% moisture and the mean weight were expressed in gram.

3.13.9 Grain yield (t ha^{-1})

Grain yield was determined from the whole plot and expressed as t ha^{-1} on 12% moisture basis. Grain moisture content was measured by using a digital moisture tester.

3.13.10 Straw yield (t ha^{-1})

Straw yield was determined from the whole plot. After threshing, the sub–sample was oven dried to a constant weight and finally converted to t ha^{-1}.

3.13.11 Biological yield (t ha^{-1})

Biological yield is the sum of grain and straw yield which was recorded into kg plot^{-1} and finally converted into t ha^{-1}. The biological yield was calculated by using the following formula: Biological yield= Grain yield + straw yield

3.13.12 Harvest index (%)

Harvest index is the ratio of the economic yield to the total biological yield of a crop. The harvest index was calculated by using the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

Where,

Economic yield = Grain yield

Biological yield = Grain yield + Straw yield

3.17 Statistical analyses

Data recorded for yield and yield contributing characters and seed quality characters were compiled and tabulated in proper form for statistical analyses. Analysis of variance was done with the help of MSTAT–C computer package programme developed by Russel (1986). The mean differences among the treatments were evaluated with DMRT test (Gomez and Gomez, 1984).

Chapter IV
Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

The present research work was to investigate the effect of P and S on the performance of growth and yield of rice cv. BRRI dhan57 under the Agro-Ecological Zone of "The Modhupur Tract", AEZ-28. The results on morpho–physiological, yield and yield attributing characters of BRRI dhan57 have been presented in Tables 1 to 8 and Figures 1 to 8. Analysis of variance (ANOVA) results was also presented in Appendices IV to VII. Among the studied characters, plant height (cm) and number of total tillers hill^{-1} were recorded at 25, 55, 85 DAT and at harvest while effective and non–effective tillers hill^{-1}, panicle length (cm), number of filled and unfilled grains panicle^{-1}, 1000–grains weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index (%) were recorded at the time of harvest and their details results were described under the following sub–headings. A detailed discussion on the presented results and possible interpretations are given in this chapter under the following headings.

4.1 Responses of P and S on morpho–physiology and yield of rice cv. BRRI dhan57

4.1.1 Plant height (cm)

4.1.1.1 Main effect of phosphorus

Plant height is one of the most efficient characters among the yield and yield contributing characters for getting the higher yield of rice due to the plant height is a key of higher straw yield. Growth of rice plant was greatly influenced by different doses of phosphorus. In this study, Application of different doses of phosphorus exerted significant difference at every stages of data recording due to Phosphorus application (Appendix IV and Fig. 1). The tallest plant (22.70, 95.81, 105.5 and 109.70 cm) was observed in 40 kg P_2O_5 (P) ha^{-1} at 25, 55, 85 DAT and at harvest, respectively which was significantly differed from other P doses. In contrast, without P (control) produced significantly the shortest plant (20.31, 88.71, 102.0 and 106.20 cm) at these stages, respectively while higher doses of P_2O_5 (60 kg ha^{-1}) were statistically close (102.70 and 106.90 cm) at 85 DAT and at harvest, respectively. These results indicated that the plant height increased progressively with the increment of growth stage and also with the increased doses of phosphorus up to 40 P_2O_5 (Fig. 1). However, plant height rapidly increased from 25 to 55 DAS and thereafter it increased gradually up to harvest. Similar findings were also obtained by Rasavel Ravichandran (2013) where they reported that plant height of rice significantly influenced by phosphorus levels where P_2O_5 @ 50 kg ha^{-1} observed the tallest plant (89.5 cm) in neutral soil. Yose (2012); Alam *et al.* (2009) and many other scientism also found significant variation in plant height due to the application of phosphorus fertilizer where plant height significantly increased with increasing the phosphorus levels.

4.1.1.2 Main effect of Sulphur

Plant height differed significantly due to the application of different level of Sulphur at 25 DAT while a non significant variation was noticed at 55, 85 DAT and at harvest due to Sulphur application (Appendix IV and Fig. 2). At 25 DAT, the tallest plant (22.79 cm) was found in 20 kg S ha^{-1} while without and higher doses of Sulphur (0 and 30 kg S ha^{-1}) recorded the statistically similar shortest plant (20.29 and 20.53 cm, respectively). However, 20 kg S ha^{-1} produced tallest plant (93.36, 105.10 and 109.40 cm) and without S obtained the shortest plant (91.16, 102.30 and 106.70 cm) at 55, 85 DAT and at harvest, respectively but they were statistically identical due to their non significant variation at these stages. On the basis of this result, it was showed that the plant height increase up to 20 kg S ha^{-1} and then it decreased. Similar observation were also observed by Islam *et al.* (2009) who conducted an experiment to evaluate the effects of different rates and sources of sulphur on the yield, yield components, nutrient content and nutrient uptake of rice (cv. BRRI dhan30). There were seven treatments consisting of four levels of sulphur (0, 8, 12 and 16 kg S ha^{-1}) applied.

The longest plant was found from 16 kg S ha^{-1} applied as gypsum when the shortest plant was noticed with S control treatment.

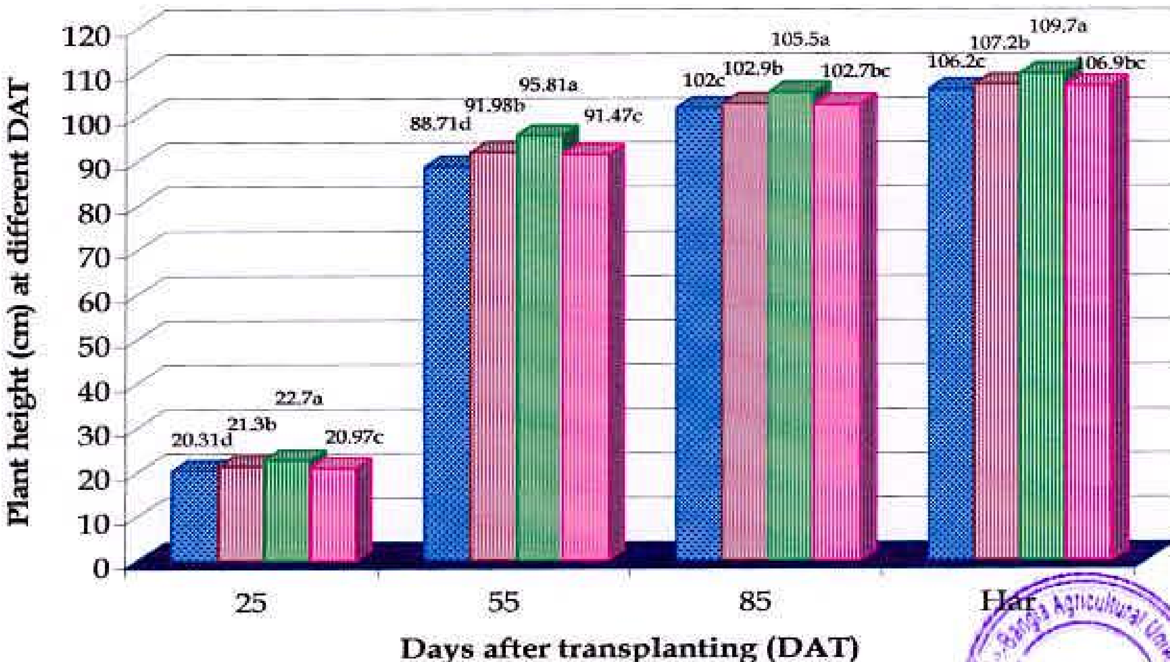

Fig. 1. Main effect of Phosphorus on plant height at different days after transplanting

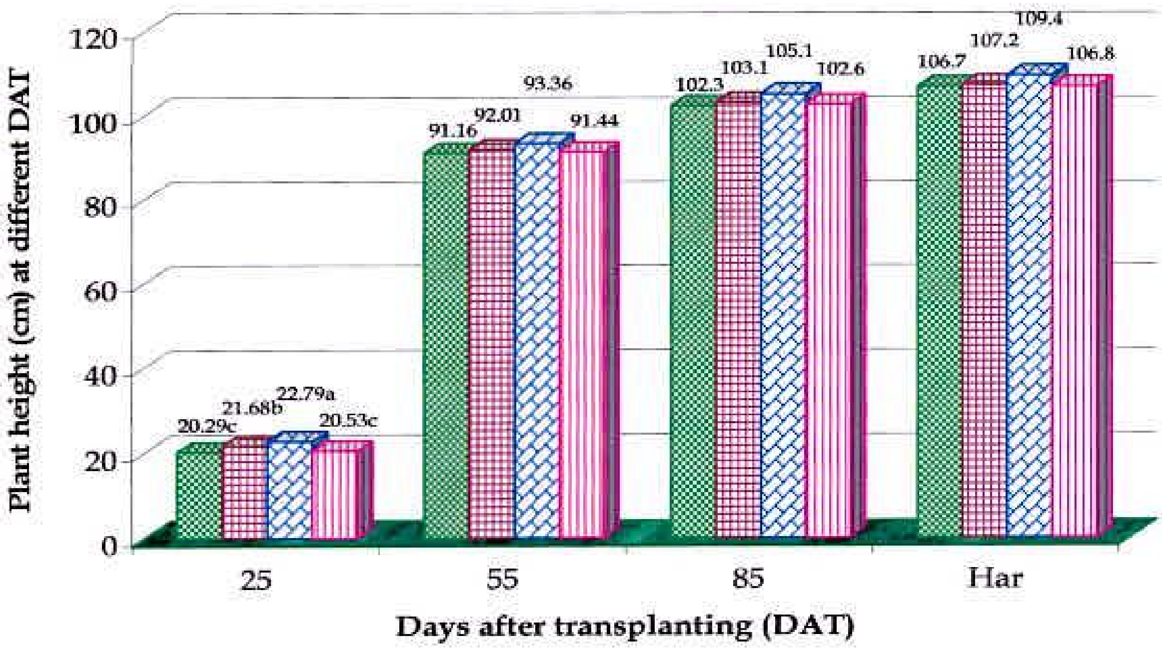

Fig. 2. Main effect of Sulphur on plant height at different days after transplanting

4.1.1.3 Interaction effect of Phosphorus and Sulphur

Interaction effect between various doses of P and S was significantly influenced at 5% level of probability on plant height at all the growth stages in this study (Appendix IV and Table 1). As a result, the tallest plant (24.17, 97.18, 107.30 and 111.60 cm) was found from the interaction treatment of 40 kg P ha^{-1} and 20 kg S ha^{-1} at 25, 55, 85 DAT and at harvest, respectively which was statistically differed from other interactions at those stages.

Table 1. Interaction effect between Phosphorus and Sulphur on plant height at different days after transplanting

Phosphorus levels (kg ha^{-1})	Sulphur levels (kg ha^{-1})	Plant height (cm) at different days after transplanting			
		25	55	85	at harvest
0	0	19.27 h	87.88 h	101.1 e	105.4 e
	10	20.66 e	88.73 h	101.8 de	105.9 e
	20	21.78 d	90.08 g	103.8 bc	108.1 bcd
	30	19.52 gh	88.16 h	101.3 de	105.5 e
20	0	20.26 ef	91.15 ef	101.8 de	106.4 de
	10	21.65 d	92.00 de	102.8 cd	106.9 cde
	20	22.77 bc	93.35 c	104.8 b	109.1 b
	30	20.51 ef	91.43 ef	102.3 de	106.5 de
40	0	21.67 d	94.97 b	104.6 b	108.9 bc
	10	23.06 b	95.83 b	105.3 b	109.4 b
	20	24.17 a	97.18 a	107.3 a	111.6 a
	30	21.91 d	95.25 b	104.8 b	109.0 b
60	0	19.94 fg	90.63 fg	101.8 de	106.0 de
	10	21.33 d	91.49 ef	102.5 cde	106.6 de
	20	22.44 c	92.84 cd	104.4 b	108.8 bc
	30	20.18 ef	90.91 fg	101.9 de	106.2 de
Level of significance		*	*	*	*
$LSD_{(0.05)}$		**0.5302**	**0.8375**	**1.374**	**1.817**
SX value		**0.1817**	**0.2869**	**0.4708**	**0.6224**
CV (%)		**1.48**	**0.54**	**0.79**	**1.1**

Figures followed by same letter(s) are statistically similar as per DMRT at 5%
LSD= Least significant difference; CV= Co-efficient of variation; *= Significant at 5% level of probability

Similarly, the shortest plant (19.27, 87.88, 101.10 and 105.40 cm) was found from interaction of both control fertilizers (without Phosphorus and Sulphur) at these stages, respectively whereas interaction effect of 0 kg P ha^{-1} with both 10 and 30 kg S ha^{-1} (88.73 and 105.50 cm) at 55 DAT and at harvest, respectively (Table 1). These results revealed that the interaction effect between 40 kg P and

20 kg S ha^{-1} had highly significant than other interactions to supplying the adequate soil nutrient with keeping the soil fertility, kept the favourable soil moisture, reduce the soil pH, maintenance the higher photosynthesis as well as to create the better growth condition for better growth of BRRI dhan57 in this study.

4.1.2 Number of total tillers $hill^{-1}$

4.1.2.1 Main effect of phosphorus

Tiller production are directly related to grain and straw yield in case of the more tillers produced more panicle, more grains which ultimately increase the grain and straw yield of rice. Number of total tillers $hill^{-1}$ showed significant difference at 1% level of probability due to the different application level of phosphorus at different days after transplanting (Appendix V and Fig. 3). From the Fig. 3, it was appeared that the phosphorus @ 40 kg ha^{-1} recorded the maximum total tillers $hill^{-1}$ (3.20, 14.73, 17.58 and 15.99) at 25, 55, 85 DAT and at harvest, respectively which was significantly differed from other phosphorus level (Fig. 3). In contrast, the minimum total tillers $hill^{-1}$ (2.67, 10.56, 13.63 and 11.82) was found in without phosphorus level at those stages, respectively which was also statistically differed from other interactions at these stages. These results indicated that tiller production significantly increased up to 85 DAT and thereafter it decreased at harvest due to its mortality for maturity. The result also showed that 40 kg P ha^{-1} always produced maximum number of total tillers $hill^{-1}$ at all growth stages while without phosphorus gave the lowest tiller production. The present finding of the study was agreed to the findings of Rasavel and Ravachandran (2013) who reported that the maximum number of tillers $hill^{-1}$ (17.2) was noticed with application of 50 kg P_2O_5 ha^{-1} in neutral soils. Similarly, Yose (2012) found that the tiller production increased significantly with phosphorus fertilizer. Alam *et al.* (2009) also found that the number of tillers $hill^{-1}$ differed significantly with the application of P fertilizer.

4.1.2.2 Main effect of Sulphur

Analysis of variance data regarding to tiller production $hill^{-1}$ was affected significantly due to the various application levels of Sulphur in this study at 25, 55, 85 DAT and at harvest (Appendix V and Fig. 4). Among the Sulphur levels, the maximum total tillers $hill^{-1}$ (4.07, 13.68, 16.28 and 14.95) was recorded in 20 kg S ha^{-1} at 25, 55, 85 DAT and at harvest, respectively which was significantly differed from phosphorus level (Fig. 4). On the other hand, the minimum total tillers $hill^{-1}$ (2.33, 11.35, 14.63 and 12.62) was found in without Sulhur at those stages, respectively whereas statistically identical lower total tillers $hill^{-1}$ (2.47, 11.58 and 12.85) was obtained in higher Sulphur level (30 kg ha^{-1}) at 25, 55 DAT and at harvest, respectively. However, 20 kg S ha^{-1} also showed statistically lower total tillers $hill^{-1}$ (12.08) at 55 DAT and statistically closes total tillers $hill^{-1}$ (14.73) was noticed in 60 kg P_2O_5 ha^{-1} at 55 DAT (Fig. 3). These result revealed that number of total tillers $hill^{-1}$ increased with the increasing levels of S up to 20 kg ha^{-1} after that it was decreased at 30 kg S ha^{-1}. Similarly, Increment tiller production unexpectedly significantly decreased at harvest due to the tiller mortality for higher maturity at harvest or repining stage.

4.1.2.3 Interaction effect of Phosphorus and Sulphur

A significant variation was also found during the data recording period due to interaction effect between Phosphorus and Sulphur fertilizers regarding to number of tillers $hill^{-1}$ and the analysis of variance data presented in Appendix IV in this study (Appendix V and Table 2). Among the interaction effect, 40 kg P ha^{-1} recorded the maximum total tillers $hill^{-1}$ (4.33, 16.26, 18.10 and 17.50) with the combination of 20 kg S ha^{-1} at 25, 55, 85 DAT and harvest, respectively which was statistically differed from other interactions of both fertilizers at every data recording stages. On the other hand, the minimum total tillers $hill^{-1}$ (2.07, 9.73, 13.00 and 11.00) was observed from the interaction effect between both control (without P and S) fertilizers at 25, 55, 85 DAT and at harvest, respectively which was statistically identical with the interaction effect between without phosphorus and 30 kg S ha^{-1} 85 DAT and significantly differed from other interactions at 25, 55 DAT and at harvest (Table 2).

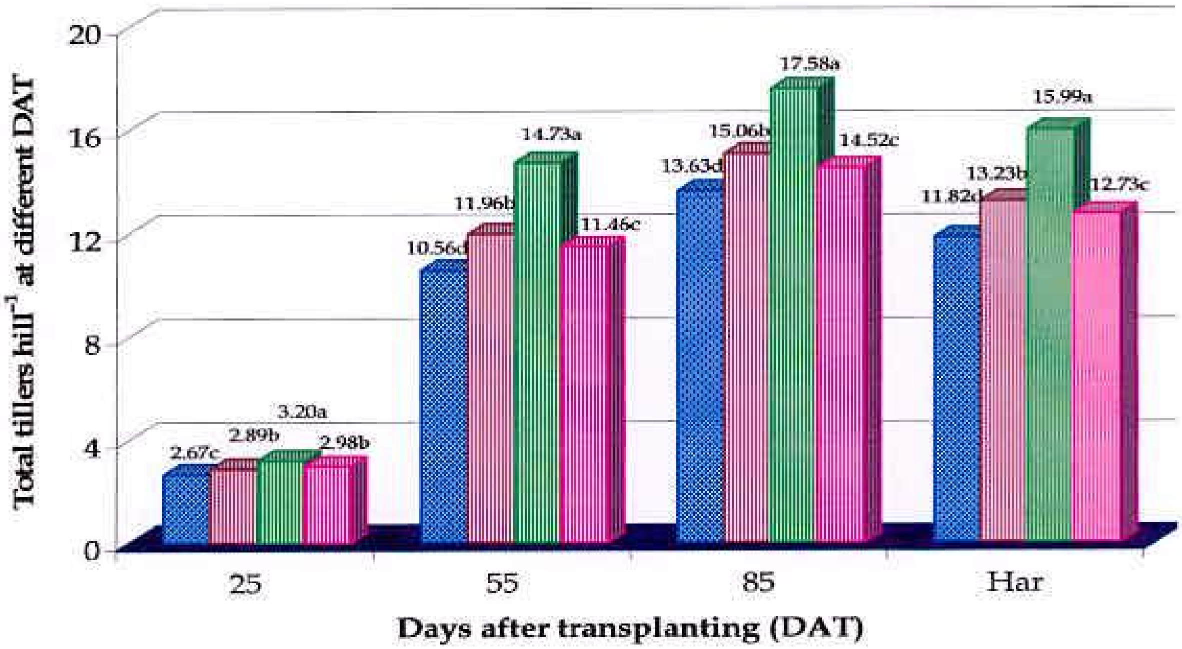

Fig. 3. Main effect of Phosphorus (P) on number of total tillers hill^{-1} at different days after transplanting

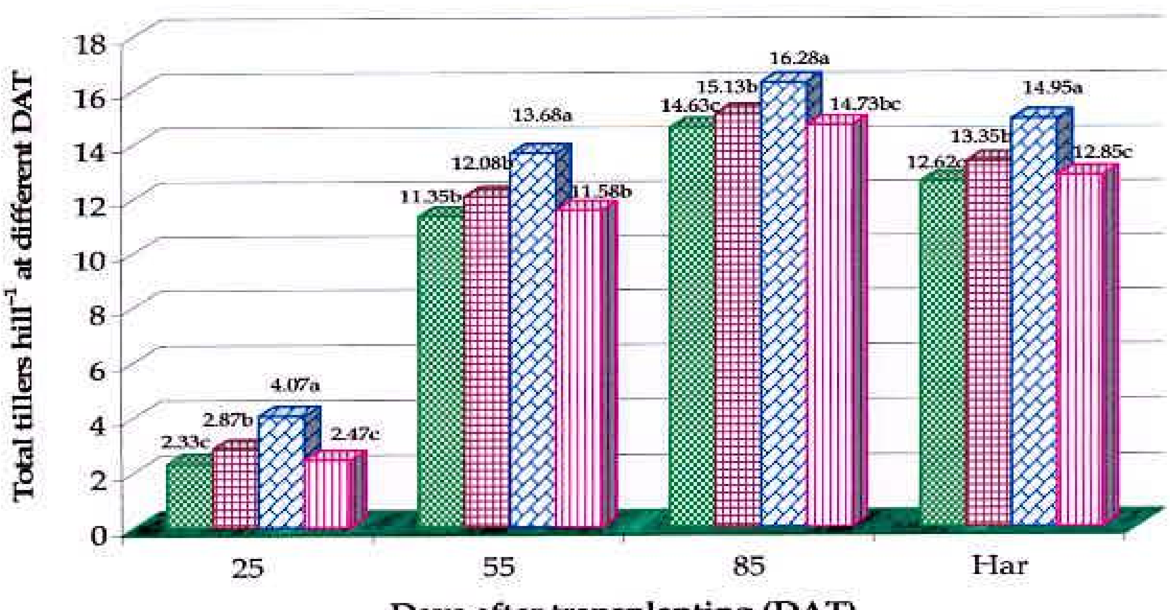

Fig. 4. Main effect of Sulphur on number of total tillers hill^{-1} at different days after transplanting

These results revealed that all the interaction treatments showed increment tillers production hill^{-1} up to 85 DAT, thereafter it decrease at harvest which might be due to the tiller mortality for maturity at harvest. The interaction treatment of 40 kg P ha^{-1} and 20 kg S ha^{-1} obtained the maximum tillers due to the proper nutrient supply to the plant which ultimately reduced the tiller mortality at harvest.

Table 2. Interaction effect between Phosphorus and Sulphur on number of total tillers hill^{-1} at different days after transplanting

Phosphorus levels (kg ha^{-1})	Sulphur levels (kg ha^{-1})	Number of total tillers hill^{-1} at DAT			
		25	55	85	at harvest
0	0	2.073 k	9.733 i	13.00 g	11.00 o
	10	2.607 fgh	10.47 ghi	13.50 fg	11.73 m
	20	3.807 c	12.07 e	14.90 d	13.33 g
	30	2.207 jk	9.967 hi	13.10 g	11.23 n
20	0	2.287 ijk	11.13 fg	14.43 de	12.40 j
	10	2.820 ef	11.87 ef	14.93 d	13.13 h
	20	4.020 bc	13.47 cd	16.33 c	14.73 e
	30	2.420 hij	11.37 efg	14.53 de	12.63 i
40	0	2.600 fgh	13.90 bc	17.20 b	15.17 d
	10	3.133 d	14.63 b	17.70 ab	15.90 b
	20	4.333 a	16.23 a	18.10 a	17.50 a
	30	2.733 efg	14.13 bc	17.30 b	15.40 c
60	0	2.377 hij	10.63 ghi	13.90 ef	11.90 l
	10	2.910 e	11.37 efg	14.40 de	12.63 i
	20	4.110 b	12.97 d	15.80 c	14.23 f
	30	2.510 ghi	10.87 gh	14.00 ef	12.13 k
Level of significance		*	*	*	ns
$LSD_{(0.05)}$		**0.2197**	**0.8409**	**0.7536**	**0.141**
SX value		**0.007528**	**0.2881**	**0.2582**	**0.0483**
CV (%)		**4.43**	**4.1**	**2.94**	**0.63**

Figures followed by same letter(s) are statistically similar as per DMRT at 5%
LSD= Least significant difference; CV= Co-efficient of variation; *= Significant at 5% level of probability

4.1.3 Number of effective tillers hill^{-1}

4.1.3.1 Main effect of phosphorus

Among the yield components, productive or effective tillers are very important for obtaining the higher grain yield of rice incase of the final yield is mainly a function of the number of panicles bearing tillers per unit area. As evident from the analysis of variance data presented in Appendix VI, effective tillers hill^{-1} exerted significant difference among the effects of different phosphorus levels (Table 3). From the Table 3, it was noticed that the maximum effective tillers hill^{-1} (13.67) was taken in 40 kg P ha^{-1} which was significantly differed from other phosphorus treatments. Similarly, without phosphorus or control treatment recorded the minimum number of effective tillers hill^{-1} (7.98) which was also statistically differed from other P_2O_5 levels. These results revealed that variation in phosphorus application ultimately gave the differentiation in tiller production. It was also observed that the production of effective tillers significantly improved with the increase of applied phosphorus levels in this study. These variation in effective tiller production may be also found due to the higher doses of phosphorus would be more efficient than lower doses of phosphorus to soil fertility, adequate N supply, reduce soil pH and initiate favourable condition for better growth as well as the maximum effective tillers production were achieved. Yose (2012) also found similar results with the present study in case of they also found significant increase of fertile tiller with phosphorus fertilizer. Similarly, Yosef (2013a, b) reported that the effective tillers hill^{-1} of rice varied significantly due to P fertilizer application where tiller production was highly responsive to phosphorus. They found that the maximum fertile tiller percentage (%) was (79.54) observed for 90 kg ha^{-1} phosphorus fertilizer and minimum of that was (66.73) obtained for (control) 0 kg ha^{-1} phosphorus fertilizer.

4.1.3.2 Main effect of Sulphur

Analysis of variance data regarding to effective tiller production hill^{-1} exerted significant difference among the effects of different Sulphur levels (Appendix VI and Table 4). Among the Sulphur levels, it was noticed that the maximum effective tillers hill^{-1} (12.12) was taken in 20 kg S ha^{-1} which was significantly differed from other Sulphur levels. In contrast, without Sulphur or control treatment recorded the minimum effective tillers hill^{-1} (9.37) which was statistically identical with the higher levels of S @ 30 kg ha^{-1} (9.47). Islam *et* *al*. (2009) also reported the similar results. They observed that the effective tillers $hill^{-1}$ was significantly influenced due to application of sulphur where 16 kg S ha^{-1} recorded the maximum effective tillers $hill^{-1}$.

4.1.3.3 Interaction effect of Phosphorus and Sulphur

The data on number of effective tillers $hill^{-1}$ was significantly influenced between the interaction effect of Phosphorus and Sulphur at harvest (Appendix VI and Table 5). The maximum number of effective tillers $hill^{-1}$ (15.53) was found from the interaction effect between 40 kg P ha^{-1} and 20 kg S ha^{-1} which was statistically differed from other interactions. In contrast, interaction effect of both control fertilizers (Phosphorus and Sulphur) obtained the minimum effective tillers $hill^{-1}$ (7.17) at harvest which was also statistically differed from other interactions. These results showed that all the interactions were statistically differed with each other whereas interaction effect of 40 kg P ha^{-1} and 20 kg S ha^{-1} were more effective to reduce the possibility of tiller mortality by supplying the proper soil nutrient to the plant at harvest which ultimately produced more effective tillers in this study.

4.1.4 Number of non effective tillers $hill^{-1}$

4.1.4.1 Main effect of phosphorus

Analysis of variance data on non effective tillers $hill^{-1}$ was presented in Appendix VI indicated significant variation due to the effect of different doses of phosphorus at harvest (Table 3). As evident from the Table 3, the maximum non effective tillers $hill^{-1}$ (3.85) was found in control or without phosphorus while the minimum non effective tillers $hill^{-1}$ (2.33) was obtained in 40 kg P ha^{-1} (Table 3). The variation in production of non effective tillers was found due to the variation in phosphorus levels which ensure the differentiation in tiller mortality possibility at harvest. These results also revealed that 40 kg ha^{-1} phosphorus was more efficient to produced minimum non effective tillers which will contribute to greater grain and straw yield. Non effective tillers did not produce any panicle as well as filled grain which ultimately decreased the final grain yield also. Similarly, Yosef (2013a, b) found that the maximum barrier tiller was (8.15) observed for (control) 0 kg ha^{-1} P fertilizer and minimum of that was (5.36) obtained for 90 kg ha^{-1} phosphorus fertilizer. Similar findings was also found by Rasavel *et al.* (2013), Yose (2012), Alam *et al.* (2009) where they found that control treatment produced significantly the maximum non effective tillers $hill^{-1}$.

4.1.4.2 Main effect of Sulphur

Number of non–effective tillers $hill^{-1}$ had revealed significant difference due to the application of Sulphur in this study (Appendix VI and Table 4). The maximum non–effective tillers $hill^{-1}$ (3.38) was taken from the higher doses of Sulphur (60 kg ha^{-1}) at harvest while lower doses of Sulphur (10 kg S ha^{-1}) and without or control Sulphur (0 kg S ha^{-1}) recorded the statistically identical second higher non effective tillers $hill^{-1}$ (3.30 and 3.25, respectively) at harvest. As a result, Sulphur@ 20 kg ha^{-1} obtained the minimum non effectively tillers $hill^{-1}$ (2.83) at harvest. The variation in production of non effective tillers was found due to the variation of application levels of S. In case of soil nutrient, soil moisture and pH, photosynthesis, Sulphur diffusion etc. varied due to the variation of Sulphur in this study.

4.1.4.3 Interaction effect of Phosphorus and Sulphur

There was a significant variation was also found due to the application of both Phosphorus and Sulphur fertilizer in respect of non effective tiller production in this study (Appendix VI and Table 5). From the Table 5, it was found that the maximum number of non effective tillers $hill^{-1}$ (3.97) was produces while phosphorus was absent but Sulphur was applied at higher rate of 30 kg ha^{-1} at harvest while this interaction treatment were statistically differed from other interactions of both fertilizers. Similarly, the minimum number of non effective tillers $hill^{-1}$ (1.97) was found in 40 kg P ha^{-1} with the combination of 20 kg S ha^{-1} which was also statistically differed from other interactions. Table 5 also showed that all the interaction were statistically significant with each other.

4.1.5 Length of panicle (cm)

4.1.5.1 Main effect of phosphorus

Panicle length was also important yield contributing characters in this study in case of the longest panicle produced significantly the more grains which will contribute to maximize the total grain and biological yield. Panicle length of BRRI dhan57 was significantly influenced by the effect of various types and doses of phosphorus at harvest (Appendix VI and Fig. 5). From the Fig. 5, it was found that the panicle length varied from 19.33 to 22.04 cm whereas the longest panicle (22.04 cm) was observed in 40 kg P ha^{-1} while control or without Phosphorus recorded the shortest panicle (19.33 cm) at harvest. These results showed that there was significant difference were found among the whole P application levels. This result is in agreement with the findings of Rasavel *et al.* (2013) who found that the longest panicle (24.9, 21.6 cm) was noticed with application of 50 kg P_2O_5 ha^{-1}, 20 kg S ha^{-1} and 10 kg Zn ha^{-1} (T_8) in neutral and alkali soils respectively. Similarly, Yosef (2013a, b) reported that panicle length varied significantly where 90 kg ha^{-1} P_2O_5 recorded the longest panicle.

4.1.5.2 Main effect of Sulphur

Panicle length varied significantly among the application of different level of Sulphur in T-aman rice (Appendix VI and Fig. 6). Among the treatments, the panicle length had higher (21.35 cm) in 20 kg S ha^{-1} which was statistically followed (close) by the application of 10 kg S ha^{-1} (20.51 cm). On the other hand, the lower length of panicle (19.96 cm) was recorded in without Sulphur which was statistically identical with higher doses (30 kg S ha^{-1}) of Sulphur (20.19 cm). Similar results were also obtained by Islam *et al.* (2009) who reported that 16 kg S ha^{-1} was more effective on panicle length of T. aman rice cv. BRRI dhan30.

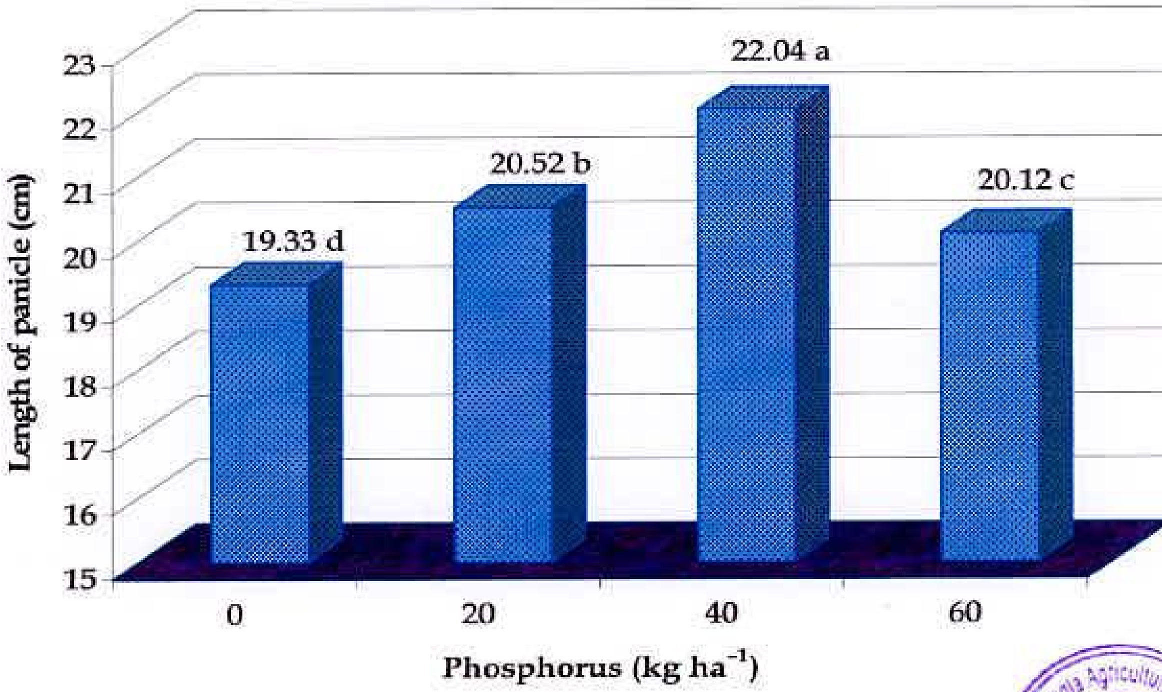

Fig. 5. Main effect of Phosphorus (P) on length of panicle at harvest

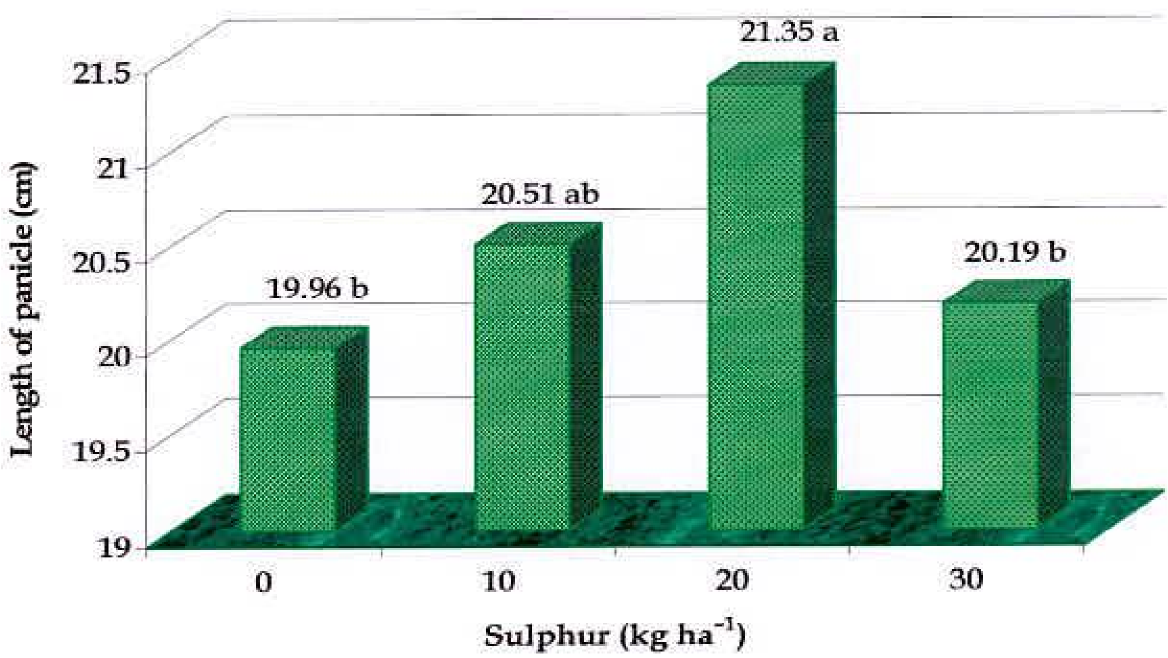

Fig. 6. Main effect of Sulphur on length of panicle at harvest

4.1.5.3 Interaction effect of Phosphorus and Sulphur

Analysis of variance data on length of panicle did not differed significantly due to the interaction effect of the studied Phosphorus and Sulphur fertilizer (Appendix VI and Table 5). Among the interaction effect, interaction effect between 40 kg P ha^{-1} and 20 kg S ha^{-1} recorded the longest panicle (23.26 cm) while interaction effect of both control fertilizer (without Phosphorus and Sulphur) recorded the shortest panicle (18.70 cm) whereas all the interaction treatments of both fertilizers were not statistically significant (Table 5).

4.1.6 Number of filled grains $panicle^{-1}$

4.1.6.1 Main effect of phosphorus

Different levels of Phosphorus increased the number of filled grains $panicle^{-1}$ of BRRI dhan 57 up to 40 kg ha^{-1} in this study which increment result regarding to filled grains $panicle^{-1}$ exerted significant different due to their (P) application (Appendix VI and Table 5). The filled grains production $panicle^{-1}$ due to different doses of phosphorus varied from 110.0 to 138.60 (Table 5). The maximum number of filled grains $panicle^{-1}$ was obtained in 40 kg P ha^{-1} which was statistically differed from other P levels. On the other hand, the minimum number of filled grains $panicle^{-1}$ was observed in without P level (control treatment) which was also statistically differed from other P levels. These results revealed that all the treatments of phosphorus were over control while P @ 40 kg ha^{-1} produced significantly the greater result regarding to filled grain production $panicle^{-1}$ in this study. In case of the treatment produced significantly the maximum total and effective tiller as well as the minimum unfilled grains production which ultimately confirmed the maximum production of filled grains $panicle^{-1}$. Rasavel *et al.* (2013) studied the similar findings with the present study. They reported that the maximum grain $panicle^{-1}$ (115.6, 108.3) was noticed with application of 50 kg P_2O_5 ha^{-1}, 20 kg S ha^{-1} and 10 kg Zn ha^{-1} (T_8) in neutral and alkali soils respectively. Similarly, Yose (2012) found that the total grain increased significantly with phosphorus fertilizer. These results was also similar to the findings of Alam *et al.* (2009) who reported that the maximum filled grains panicle^{-1} differed significantly with the application of P fertilizer while phosphorus at 72 kg ha^{-1} (P_3) showed the maximum and without P gave the lowest results.

4.1.6.2 Main effect of Sulphur

Number of filled grains panicle^{-1} did not differed significantly due to the application of different levels of Sulphur in T-aman rice cv. BRRI dhan57 in this experiment (Appendix VI and Table 4). However, he maximum filled grains panicle^{-1} (127.00) was recorded in 20 kg S ha^{-1} and minimum (119.6) was found in control S but they were not statistically differed (Table 4).

4.1.6.3 Interaction effect of Phosphorus and Sulphur

Analysis of variance data regarding to filled grains panicle^{-1} presented in Appendix VI and indicated significant variation due to the interaction effect between Phosphorus and Sulphur (Table 5). Among the interaction treatments, the maximum number of filled grains panicle^{-1} (141.40) was found in interaction of 40 kg P ha^{-1} and 20 kg S ha^{-1} which was statistically significant from other interactions. Similarly, interaction effect between both control fertilizers (without Phosphorus and Sulphur) obtained the minimum number of filled grains panicle^{-1} (108.8) which was statistically more or less similar with the interactions of without Phosphorus with 30 kg S ha^{-1} (108.90) and 10 kg S ha^{-1}(109.4).

4.1.7 Number of unfilled grains panicle^{-1}

4.1.7.1 Main effect of phosphorus

The variations in the number of unfilled grains panicle^{-1} due to different doses of Phosphorus were significant at harvest in this study (Appendix VI). The significant variation result regarding to unfilled grains panicle^{-1} was presented in Table 3 where it was showed that the unfilled grains panicle^{-1} varied from 8.45 to 15.93. The maximum unfilled grains panicle^{-1} was produced due to 40 kg P ha^{-1} and the lowest unfilled grains panicle^{-1} was obtained in 20 kg S ha^{-1}

whereas all the Phosphorus levels were statistically significant with each other (Table 3). The variation in unfilled grains panicle^{-1} was found due to the variation in phosphorus level. Phosphorus @ 40 kg ha^{-1} produced significantly the maximum effective tillers and more panicle which confirmed the minimum unfilled grains and it will be contribute to maximize the grain production of rice cv. BRRI dhan57 in this study. Similar findings were also obtained by Alam *et al.* (2009). They found that unfilled grains panicle^{-1} differed significantly with the application of P fertilizer while it was the maximum in 72 kg P ha^{-1} and minimum in without P.

Table 3. Main effect Phosphorus on effective and non effective tillers hill^{-1} and filled and unfilled grains panicle^{-1} at harvest

Phosphorus levels (kg ha^{-1})	Number of effective tillers hill^{-1}	Number of non effective tillers hill^{-1}	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}
0	7.975 d	3.850 a	110.0 d	15.93 a
20	10.02 b	3.208 c	120.9 b	13.21 c
40	13.67 a	2.325 d	138.6 a	8.450 d
60	9.342 c	3.383 b	116.9 c	14.03 b
Level of significance	**	**	**	**
$LSD_{(0.05)}$	**0.08837**	**0.02664**	**0.9873**	**0.2485**
SX value	**0.03028**	**0.009129**	**0.3383**	**0.08515**
CV (%)	**1.03**	**1.14**	**0.96**	**2.29**

Figures followed by same letter(s) are statistically similar as per DMRT at 5%
LSD= Least significant difference; CV= Co-efficient of variation; *= Significant at 5% level of probability

4.1.7.2 Main effect of Sulphur

Number of unfilled grains panicle^{-1} differed significantly due to the main effect of Sulphur (Appendix VI and Table 4). Among the Sulphur treatments, the maximum number of unfilled grains panicle^{-1} (13.42) was recorded in 10 kg S ha^{-1} which was statistically followed by without Sulphur (13.00) and higher levels of Sulphur @ 30 kg S ha^{-1} (13.17) whereas without Sulphur and 30 kg S ha^{-1} were statistically identical to produced more unfilled grains. As a result, the minimum number of unfilled grains panicle^{-1} (12.04) was recorded in 20 kg S ha^{-1} which was also statistically followed by without and 30 kg S ha^{-1} (Table 4). These results showed that 20 kg S ha^{-1} had highly significant to reduce unfilled grains due to maximum productive tillers and more filled grains were obtained under this treatment.

Table 4. Main effect Sulphur on effective and non effective tillers hill^{-1} and filled and unfilled grains panicle^{-1} at harvest

Sulphur levels (kg ha^{-1})	Number of effective tillers hill^{-1}	Number of non effective tillers hill^{-1}	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}
0	9.367 c	3.250 b	119.6	13.00 ab
10	10.05 b	3.300 b	120.2	13.42 a
20	12.12 a	2.833 c	127	12.04 b
30	9.467 c	3.383 a	119.7	13.17 ab
Level of significance	**	**	**ns**	*
$LSD_{(0.05)}$	**0.3222**	**0.07738**	**8.093**	**1.292**
SX value	**0.09309**	**0.02236**	**2.339**	**0.3735**
CV (%)	**1.03**	**1.14**	**0.96**	**2.29**

Figures followed by same letter(s) are statistically similar as per DMRT at 5%
LSD= Least significant difference; CV= Co-efficient of variation; *= Significant at 5% level of probability

4.1.7.3 Interaction effect of Phosphorus and Sulphur

The data on unfilled grains panicle^{-1} showed significant difference among the interaction effect between Phosphorus and Sulphur (Appendix VI and Table 5). The unfilled grains panicle^{-1} varied from 7.87 to 16.27 due to interaction effect of Phosphorus and Sulphur fertilizers. The minimum number of unfilled grains panicle^{-1} (16.27) was found in interaction of 0 kg P ha^{-1} and 10 kg S ha^{-1} which was followed by the interaction effects of both 0 kg P and S ha^{-1} (15.85) and 0 kg P ha^{-1} and 30 kg S ha^{-1} (16.02) whereas interaction effect of 0 kg P ha^{-1} and 10 kg S ha^{-1} and 0 kg P ha^{-1} and 30 kg S ha^{-1} were statistically identical to produced unfilled grains $panicle^{-1}$. On the other hand, interaction effect between 40 kg P ha^{-1} and 20 kg S ha^{-1} obtained the minimum number of unfilled grains $panicle^{-1}$ (7.87) which was statistically differed from other interactions (Table 5).

Table 5. Interaction effect between Phosphorus and Sulphur on number of effective and non effective tillers hill^{-1}, length of panicle and number of filled and unfilled grains panicle^{-1} production at harvest

Phosphorus levels (kg ha^{-1})	Sulphur levels (kg ha^{-1})	Number of effective tillers hill^{-1}	Number of non effective tillers hill^{-1}	Length of panicle (cm)	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}
0	0	7.167 o	3.833 c	18.70 k	108.8 h	15.85 ab
	10	7.833 m	3.900 b	19.49 i	109.4 h	16.27 a
	20	9.633 h	3.700 d	19.93 g	112.8 g	15.58 b
	30	7.267 n	3.967 a	19.18 j	108.9 h	16.02 ab
20	0	9.100 j	3.300 h	20.02 fg	117.6 e	13.55 fg
	10	9.800 g	3.333 h	20.48 e	118.2 e	13.97 def
	20	11.97 e	2.767 j	21.42 c	130.2 c	11.62 h
	30	9.200 i	3.433 g	20.17 f	117.8 e	13.72 ef
40	0	12.80 d	2.367 l	21.43 c	137.4 b	8.450 i
	10	13.43 b	2.467 k	21.89 b	138.0 b	8.867 i
	20	15.53 a	1.967 m	23.26 a	141.4 a	7.867 j
	30	12.90 c	2.500 k	21.58 c	137.6 b	8.617 i
60	0	8.400 l	3.500 f	19.70 h	114.5 fg	14.15 cde
	10	9.133 j	3.500 f	20.16 f	115.0 f	14.57 c
	20	11.33 f	2.900 i	20.78 d	123.6 d	13.08 g
	30	8.500 k	3.633 e	19.85 gh	114.6 fg	14.32 cd
Level of significance		*	**	**	**	**
$LSD_{(0.05)}$		**0.05329**	**0.05329**	**0.1685**	**1.975**	**0.4971**
SX value		**0.01826**	**0.01826**	**0.05774**	**0.6765**	**0.1703**
CV (%)		**1.03**	**1.14**	**0.5**	**0.96**	**2.29**

Figures followed by same letter(s) are statistically similar as per DMRT at 5%

LSD= Least significant difference; CV= Co-efficient of variation; *= Significant at 5% level of probability

4.1.8 Thousand–grain weight (g)

4.1.8.1 Main effect of phosphorus

Analysis of variance data regarding to thousand grain weight differed significantly due to the main effect of Phosphorus fertilizer which analysis of variance data was presented in Appendix VII and the significant variance results was also presented in Fig. 7. From the Fig. 7, it was found that the different phosphorus levels increased the thousand-grain weight of BRRI dhan57 over control whereas 40 kg Phosphorus ha^{-1} noticed the highest weight of thousand grains (30.75 g). In contrast, without P levels recorded the lowest weight of thousand grains (26.36 g). Figure 7, also showed that all the P levels including control obtained the statistically significant variation with each other whereas all the P levels were over control. These results revealed that application of 40 kg P ha^{-1} had highly effective to produced adequate soil nutrients and manufacture favourable growing condition for rice plant which was helpful to produced more filled grain, larger grain, longest panicle as well as higher weight of grain. Similarly Yose (2012) found that the 1000-grain weight increased significantly with phosphorus fertilizer. Alam *et al.* (2009) also found similar results with my study where they reported that 1000-grain weight differed significantly with the application of P fertilizer while highest weight of 1000-grain were taken from phosphorus at 72 kg ha^{-1} and without P gave the lowest weight.

4.1.8.2 Main effect of Sulphur

Thousand grains weight did not differ significantly due to the application of different levels of Sulphur in this study (Appendix VII and Fig. 8). As a result all the levels of Sulphur including control were statistically identical for obtaining the 1000 grain weight due to non significant variation (Fig. 8).

4.1.8.3 Interaction effect of Phosphorus and Sulphur

Analysis of variance data on thousand grain yield varied significantly among the interactions effect between the application of Phosphorus and Sulphur

(Appendix VII and Table 6). From the Table 6, it was observed that the highest thousand grain weight (31.63 g) was found in 40 kg P ha^{-1} and 20 kg S ha^{-1} which was statistically differed from other interactions. On the other hand, the lowest weight of 1000 grain (25.88 g) was found from the interaction effect between without phosphorus and without Sulphur (both 0 kg ha^{-1}) where they were closely followed by both 10 and 30 kg S ha^{-1} with without P levels (26.42 and 26.05 g, respectively) but they were not statistically identical (Table 16).

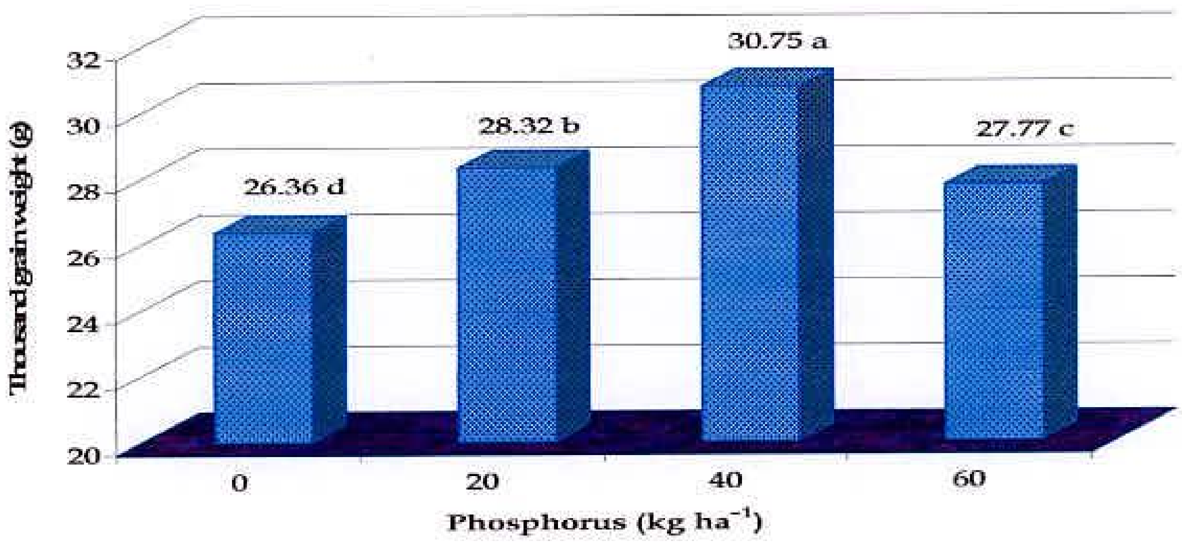

Fig. 7. Main effect of Phosphorus (P) on thousand grain weight at harvest

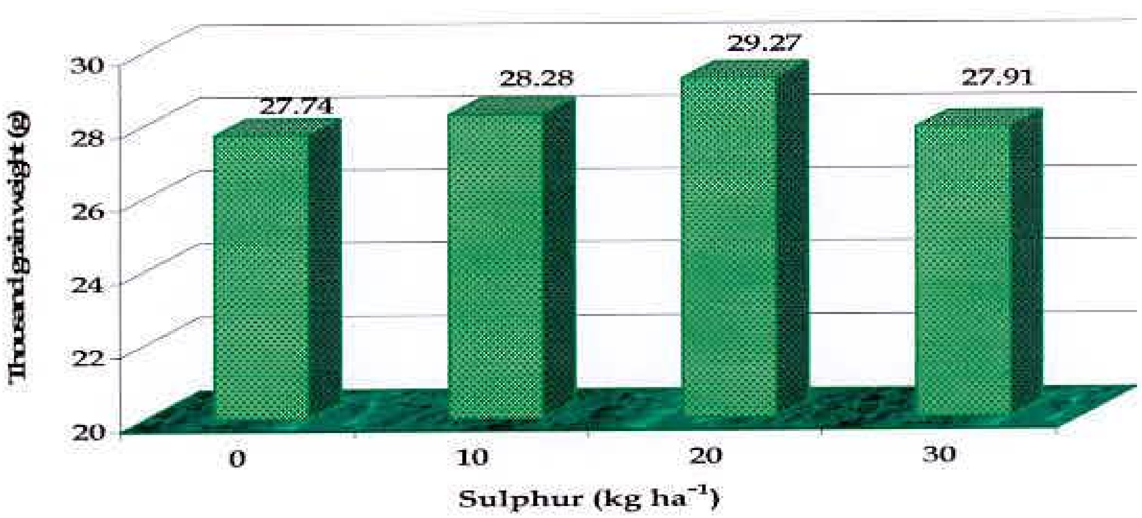

Fig. 8. Main effect of Sulphur on thousand grain weight at harvest

4.1.9 Grain yield (t ha^{-1})

4.1.9.1 Main effect of phosphorus

Analysis of variance in data was presented in Appendix VII where it was found that the grain yield of BRRI dhan57 was significantly influenced due to the different levels of phosphorus in this study (Table 6). From the Table 6, it was found that the grain yield due to various levels of phosphorus ranged from 3.77 to 5.12 t ha^{-1}. All the treatments showed higher grain yield over control (Table 6). The highest grain yield (5.12 t ha^{-1}) was found in 40 kg P ha^{-1} which was statistically differed from other P levels. In contrast, the lowest grin yield (3.77 t ha^{-1}) was recorded in without P levels in this study which was also statistically differed from other P levels. The yield contributing characters like tiller production $hill^{-1}$, filled grains $panicle^{-1}$, longest panicle, larger sizes grain were also found in 40 kg P ha^{-1} treatment which probably contributed to obtained the higher grain yield in this treatment i.e. 40 kg P ha^{-1}. Similar findings were also obtained by Srivastava *et al.* (2014) on basmati rice with the effect of Zn and P levels. The highest grain yields of basmati rice were obtained with soil application of 17.5 kg P ha^{-1}. This results are also agreed with Rasavel *et al.* (2013) who also found that the highest grain yield (5216, 4678 kg ha^{-1}) was noticed with application of 50 kg P_2O_5, 20 kg S and 10 kg Zn ha^{-1} in neutral and alkali soils respectively. Yosef (2013a) also reported that the maximum grain yield (4540) was observed for 90 kg ha^{-1} phosphorus fertilizer and minimum of that was (3800) obtained for (control) 0 kg ha^{-1} phosphorus fertilizer. Similarly Yose (2012) found that yield increased significantly with phosphorus fertilizer. Similar study were also obtained by Alam *et al.* (2009) in rice where they found that grain yield differed significantly with the application of P fertilizer while phosphorus at 72 kg ha^{-1} (P_3) produced the highest grain yield (7.23 t ha^{-1}) of rice. Plants grown without added P gave the lowest grain yield (4.99 t ha^{-1}).

4.1.9.2 Main effect of Sulphur

Grain yield varied significantly due to different levels of Sulphur in this study where significant variation grain yield were varied from 3.96 to 4.75 t ha^{-1} (Appendix IV and Table 7). The highest grain yield (4.75 t ha^{-1}) was recorded in 20 kg S ha^{-1} which was statistically significant with other S levels and also over control. The lowest grain yield (3.96 t ha^{-1}) was recorded in without S level while it was statistically identical with 30 kg S ha^{-1} (4.07 t ha^{-1}). On the basis of this results investigation it was observed that the increasing levels of Sulphur increased the grain yield up to 20 kg S ha^{-1}. Similar trend was also observed by Islam *et al.* (2009) who reported that the highest grain yield of 5293 kg ha^{-1} was obtained from 16 kg S ha^{-1} applied as gypsum. The lowest grain yield (4200 kg ha^{-1}) was recorded with S control treatment.

4.1.9.3 Interaction effect of Phosphorus and Sulphur

A significant variation was found due to the interaction effect various doses of between Phosphorus and Sulphur application (Appendix VII and Table 8). From the Table 8, it was found that the grain yield varied from 3.50 to 5.64 t ha^{-1} whereas the higher yield of grain was found in 40 kg P ha^{-1} and 20 kg S ha^{-1} which was statistically significant among other interactions. In contrast, interaction effect between both control of P and S (0 kg P ha^{-1} and 0 kg S ha^{-1}) recorded the lowest yield of grain (3.50 t ha^{-1}) which was closely followed by 0 kg P ha^{-1} with both 10 and 30 kg S ha^{-1} (3.92 and 3.88 t ha^{-1}) whereas both interactions of 0 kg P ha^{-1} + 10 kg S ha^{-1} and 0 kg P ha^{-1} + 30 kg S ha^{-1} were statistically identical (Table 8). These result revealed that soil application of both control (P and S) obtained the lower yield of rice due to its minimum tiller and effective tillers production, minimum filled grain, shortest panicle and lower sizes grain were obtained under those treatments. Similarly, interaction effect between 40 kg P ha^{-1} and 20 kg S ha^{-1} noticed the higher grain yield due to its higher production of total and effective tillers $hill^{-1}$, maximum filled grains $panicle^{-1}$, longest panicle and larger sizes grain of the studied rice cultivar.

4.1.10 Straw yield (t ha^{-1})

4.1.10.1 Main effect of phosphorus

Effect of various doses of phosphorus was significantly influenced on the production of straw of BRRI dhan57 in this study which analysis of variance data was present in Appendix VII. The significant result of straw yield was also present in Table 6 where the straw yield ranged from 7.05 to 8.39 t ha^{-1} due to the phosphorus levels while all the phosphorus levels gave higher straw yield over control. The highest straw yield (8.39 t ha^{-1}) was found in 40 kg P ha^{-1} while control P fertilizer or without phosphorus noticed the lowest straw yield (7.05 t ha^{-1}). The straw yield of 7.52 and 7.29 t ha^{-1} were found in 20 and 60 kg P ha^{-1}, respectively. The results revealed that the application of 40 kg P ha^{-1} as soil application exerted pronounced effect in producing higher straw yields of BRRI dhan 57. This might be due to the phosphorus increase strength of rice, prevent lodging and increase resistance to pest which ultimately results higher yield of straw. Beside, the variation in straw yield also might be due to the variation in plant height and tiller production which results were also similar to Rasavel and Ravichandran (2013) who found that the highest straw yields (6123, 5642 kg ha^{-1}) was noticed with application of 50 kg P_2O_5, 20 kg S and 10 kg Zn ha^{-1} in neutral and alkali soils respectively. Similarly, Alam *et al.* (2009) found that the straw yield differed significantly with the application of P fertilizer while phosphorus at 72 kg ha^{-1} (P_3) produced the highest straw yield of rice.

4.1.10.2 Main effect of Sulphur

Different levels of Sulphur differed significantly on straw yield of T-aman rice (Appendix VII and Table 7). The highest straw yield (8.08 t ha^{-1}) was recorded in 420 kg S ha^{-1} which was statistically significant with other S levels. In contrast, the lowest straw yield (7.18 t ha^{-1}) was recorded in control S fertilizer which was statistically identical with 30 kg S ha^{-1} (7.29 t ha^{-1}). These result revealed that straw yield were more significant in 20 kg S ha^{-1} and thereafter it decreased at 30 kg S ha^{-1}. Similarly, Islam *et al.* (2009) reported that the highest straw yield of 6380 kg ha^{-1} was obtained from 16 kg S ha^{-1} applied as gypsum and the lowest straw yield (4963 kg ha^{-1}) was recorded with S control treatment.

4.1.10.3 Interaction effect of Phosphorus and Sulphur

Straw yield was significantly influenced by the interactions effect of studied Phosphorus and Sulphur fertilizers (Appendix VII and Table 8). From the Table 8, it was found that the straw yield varied from 6.72 to 8.97 t ha^{-1} due to the interaction treatments where the higher yield of straw (8.97 t ha^{-1}) was found in 40 kg P and 20 kg S ha^{-1} while the lowest yield of straw (6.72 t ha^{-1}) was recorded in interaction of both control fertilizers (P and S) and it was closely followed by the interaction of 0 kg P and 30 kg S ha^{-1} (6.83 t ha^{-1}). These result revealed that both control fertilizers (without Phosphorus and Sulphur) were less efficient to produced straw yield in case of the shortest plant was achieved under this interaction. Besides, higher doses of phosphorus as soil or foliar application in combined with soil application of sulphur produced tallest plant and more tillers which ensure the higher straw yield in this study.

4.1.11 Biological yield (t ha^{-1})

4.1.11.1 Main effect of phosphorus

Biological yield is a summation yield of grain and straw which was significantly affected by the application of different doses of phosphorus (Appendix VII and Table 6). The highest biological yield (13.51 t ha^{-1}) was found in 40 kg P ha^{-1} while the lowest biological yield (10.81 t ha^{-1}) was recorded in control or without Phosphorus. So, the biological yield ranged was 10.81 to 13.51 t ha^{-1} due to the phosphorus application in this study. The biological yield of 11.77 and 11.31 t ha^{-1} were also found in 20 kg and 60 kg P ha^{-1}, respectively. The results revealed that all the treatments were statistically significant with each other and P @ 40 kg ha^{-1} obtained the greater biological yield incase of the tallest plant, maximum total tillers and longest panicle were achieved under this P level. Yosef, (2013b) also found significant variation in biological yield due to phosphorus application where they reported that maximum biological yield was (9120) that observed for 90 kg ha^{-1} phosphorus fertilizer and minimum of these was (7638) obtained for (control) 0 kg ha^{-1} phosphorus fertilizer. Similarly, significant variation in biological yield of rice was also reported by Rasavel *et al.* (2013), Yose (2012), Alam *et al.* (2009).

4.1.11.2 Main effect of Sulphur

A significant variation was found due to the effect of Sulphur as soil application in respect of biological yield (Appendix VII and Table 7). From the Table 7, it was found that the biological yield had higher (12.82 t ha^{-1}) in 20 kg S ha^{-1} than that of other S levels and also over control. However, it was closely followed by 10 kg S ha^{-1} (12.09 t ha^{-1}). Similarly, the lowest biological yield (11.14 t ha^{-1}) was observed in 0 kg S ha^{-1} (control) while 30 kg S ha^{-1} produced statistically similar lower biological yield (11.36 t ha^{-1}). The variation result on biological yield was found due to the variation in Sulphur which result supported by Khan *et al.* (2012) where they found that significant increase in biological and paddy was recorded with foliar KNO_3 @ 1.5% and 2% over soil applied K_2SO_4. Use of 65 mg K Kg soil plus spraying with 5% K_2SO_4 solution was most effective in biological yield which was reported by Ebrahimi *et al.* (2012a) which results was also supported by Bahmanyare and Soodaee (2010) and they found that biological yield was significantly affected by K fertilization. Similarly, Bahmaniar *et al.* (2007) also found that the applied sulphur had positive effects on biological yield.

4.1.11.3 Interaction effect of Phosphorus and Sulphur

Biological yield was also significantly influenced among the interactions effect between the studied phosphorus and sulphur fertilizer (Appendix VII and Table 8). As a result, significantly the highest biological yield (14.60 t ha^{-1}) was obtained from the interaction effect of 40 kg P and 20 kg S ha^{-1} which was statistically differed from other interactions. Similarly, the lowest biological yield (10.21 t ha^{-1}) was recorded in interaction of both control fertilizers (without phosphorus and Sulphur) which was closely followed by 0 kg P ha^{-1} × 30 kg S ha^{-1} (10.44 t ha^{-1}) and 60 kg P ha^{-1} × 0 kg S ha^{-1} (10.60 t ha^{-1}) but they were not statistically identical. These result revealed that the phosphorus @ 40 kg ha^{-1} × 20 kg S ha^{-1} recorded the maximum biological yield in case of the higher grain and straw yield were obtained in those treatments.

4.1.12 Harvest index (%)

4.1.12.1 Main effect of phosphorus

Application of phosphorus as soil and foliar application at various levels showed significant variation in respect of harvest index in the present study (Appendix VII and Table 6). From the Table 6, it was appeared that the highest harvest index (37.85%) was found in 40 kg P ha^{-1} in case of the higher yield of grain and straw as well as maximum biological yield were found under this treatment. Similarly, the control treatment observed the lowest harvest index (34.82%) due to its lowest yield of grain and straw as well as minimum biological yield were achieved in this treatment. Another treatment also showed significant effect while harvest index of 36.03 and 35.47% were found in 20 and 60 kg P ha^{-1}, respectively (Table 6). These results revealed that the variation in harvest index was found due the variation in phosphorus levels. These were similar to Yosef (2013b) whereas they found that the maximum harvest index was (47.92) observed for 90 kg ha^{-1} phosphorus fertilizer and minimum of that was (47.79) obtained for (control) 0 kg ha^{-1} phosphorus fertilizer.

Table 6. Main effect Phosphorus on 1000-grain weight, yield characters and HI at harvest

Phosphorus levels (kg ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
0	3.768 d	7.047 d	10.81 d	34.82 c
20	4.247 b	7.523 b	11.77 b	36.03 b
40	5.116 a	8.393 a	13.51 a	37.85 a
60	4.016 c	7.294 c	11.31 c	35.47 bc
Level of significance	**	**	**	**
$LSD_{(0.05)}$	**0.5958**	**0.07993**	**0.2638**	**0.7164**
SX value	**0.2041**	**0.02739**	**0.09037**	**0.2455**
CV (%)	**1.65**	**1.26**	**2.65**	**2.36**

Figures followed by same letter(s) are statistically similar as per DMRT at 5%
LSD= Least significant difference; CV= Co-efficient of variation; *= Significant at 5% level of probability

4.1.12.2 Main effect of Sulphur

Harvest index represent comparative yield performance between grain and straw yield. It was also indicate the percent grain yield on the basis of biological yield. The data on harvest index was significantly influenced by the Sulphur application in this study (Appendix VII). Sulphur @ 20 kg ha^{-1} recorded the highest harvest index (36.90%). The lowest harvest index (35.45%) was observed in without Sulphur which was statistically similar to 30 kg S ha^{-1} (35.71%). However, 10 kg S ha^{-1} obtained harvest index of 36.11% which was statistic lay close to both higher and lower harvest index in this study (Table 6). These results revealed that harvest index differed significantly due to the significant differences of the studied Sulphur application and also the variation of grain and straw yield as well as biological yield.

Table 7. Main effect Sulphur on 1000-grain weight, yield characters and HI at harvest

Sulphur levels ($kg\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest index (%)
0	3.958 c	7.177 c	11.14 b	35.45 b
10	4.375 b	7.713 b	12.09 ab	36.11 ab
20	4.745 a	8.075 a	12.82 a	36.90 a
30	4.068 c	7.293 c	11.36 b	35.71 b
Level of significance	**	**	*	*
$LSD_{(0.05)}$	**0.1842**	**0.279**	**1.369**	**0.8405**
SX value	**0.05323**	**0.08062**	**0.3955**	**0.2429**
CV (%)	**1.65**	**1.26**	**2.65**	**2.36**

Figures followed by same letter(s) are statistically similar as per DMRT at 5%
LSD= Least significant difference; CV= Co-efficient of variation; *= Significant at 5% level of probability

4.1.12.3 Interaction effect of Phosphorus and Sulphur

Analysis of variance data regarding to harvest index was significantly influenced by the interaction effect of the studied Phosphorus and Sulphur fertilizers (Appendix VII and Table 8). Table 8 indicated that the harvest index varied from 34.24 to 38.59% where the interaction treatment of 40 kg P ha^{-1} and 20 kg S ha^{-1} recorded the highest harvest index (38.59%) which was closely followed by the interactions effect of 40 kg P ha^{-1} × 10 kg S ha^{-1} (37.83%), 20 kg P ha^{-1} × 20 kg S ha^{-1} (37.18%), 40 kg P ha^{-1} × 0 kg S ha^{-1} (37.39%) and 40 kg P ha^{-1} × 30 kg S ha^{-1} (37.58%) whereas 20 kg P ha^{-1} × 20 kg S ha^{-1}, 40 kg P ha^{-1} × 0 kg S ha^{-1} and 40 kg P ha^{-1} × 30 kg S ha^{-1} were statistically identical. In contrast, the lowest harvest index (34.24%) was recorded in both control fertilizers which was also closely followed by the maximum interactions of both fertilizers among the rest interaction effects. The variation in harvest index was found due to the variation yield of grain, straw and biological yield and also the variation in fertilizer levels.

Table 8. Interaction effect between Phosphorus and Sulphur on 1000-grain weight, yield characters and HI at harvest

P levels (kg ha^{-1})	S levels (kg ha^{-1})	Thousand grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
0	0	25.88 i	3.497 k	6.717 l	10.21 l	34.24 f
	10	26.42 ghi	3.914 gh	7.252 gh	11.17 ghij	35.05 def
	20	27.08 fgh	4.053 f	7.387 fg	11.44 fgh	35.44 def
	30	26.05 hi	3.607 jk	6.833 kl	10.44 kl	34.55 ef
20	0	27.69 f	3.877 gh	7.093 hi	10.97 hijk	35.33 def
	10	28.23 ef	4.293 e	7.631 e	11.92 ef	36.00 cde
	20	29.48 cd	4.833 c	8.160 c	12.99 c	37.18 abc
	30	27.86 ef	3.987 fg	7.210 h	11.20 ghi	35.60 def
40	0	30.22 bc	4.767 c	7.983 d	12.76 cd	37.39 abc
	10	30.76 ab	5.185 b	8.523 b	13.71 b	37.83 ab
	20	31.63 a	5.637 a	8.967 a	14.60 a	38.59 a
	30	30.39 bc	4.877 c	8.100 cd	12.98 c	37.58 abc
60	0	27.16 fgh	3.693 ij	6.913 jk	10.60 jkl	34.83 def
	10	27.69 f	4.109 f	7.447 f	11.56 fg	35.56 def
	20	28.90 de	4.457 d	7.787 e	12.24 de	36.39 bcd
	30	27.32 fg	3.803 hi	7.030 ij	10.83 ijk	35.11 def
Level of sig.		*	**	*	*	*
$LSD_{(0.05)}$		**1.025**	**0.1192**	**0.1599**	**0.5275**	**1.433**
SX value		**0.3512**	**0.04082**	**0.05477**	**0.1807**	**0.4909**
CV (%)		**2.15**	**1.65**	**1.26**	**2.65**	**2.36**

Figures followed by same letter(s) are statistically similar as per DMRT at 5%
LSD= Least significant difference; CV= Co–efficient of variation; *= Significant at 5% level of probability

4.2 Responses of Phosphorus and Sulphur on nutrients content by grain and straw

4.2.1 Main effect of Phosphorus

Nitrogen (N), Phosphorus (P), Potassium (K) and Sulphur (S) content by grain and straw of BRRI dhan57 were showed significant difference due to various Phosphorus levels (Appendix VIII and Table 9). Among the treatments, the highest N, P, K and S nutrient content by grain (0.3540, 1.708, 0.3179 and 1.561%, respectively) and straw (0.1160, 0.8881, 0.0929 and 0.2894%, respectively) were recorded in 40 kg P ha^{-1} while it was statistically differed from other P levels. However, statistically close N and S content by straw (0.1080 and 0.2755%, respectively) was also observed in 20 kg P ha^{-1} while 60 kg P ha^{-1} was also statistically similar to obtained S content by straw (0.2648%). On the other hand, The lowest content of N, P, K and S by grain (1.313, 0.2439 and 1.409%, respectively) and straw (0.6089, 0.0688 and 0.2442%, respectively) were taken in 0 kg P ha^{-1} while 60 kg P ha^{-1} while 60 kg P ha^{-1} produced statistically more or less similar lower K content by grain (0.2754 and 0.291%, respectively). However, 0 kg P ha^{-1} recorded the lower N content by straw (0.0892%) but N content by grain had lower (0.3060%) in 60 kg P ha^{-1}. Phosphorus @! 20 and 60 kg ha^{-1} further produced statistically identical lower K (0.0759 and 0.0736%, respectively) content by straw and statistically close S content by straw (0.2755 and 0.2648%, respectively). The P content in rice plant at different growth stages increased progressively with an increase of P levels for both the varieties which was reported by Islam *et al.* (2008). Similarly, Khandaker (2003) found that N uptake observed significantly differed. P and K content in grain and straw were found significnatly different among the P treated plants. Similar results also noted in case of total P and K uptake.

Table 9. Main effect of Phosphorus on nutrients content by grain and straw

P levels (kg ha^{-1})	N content		P content		K content		S content	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
0	0.3090 c	0.0950 c	1.313 c	0.6089 b	0.2439 b	0.0688 b	1.409 d	0.2442 b
20	0.3220 b	0.1080 ab	1.362 b	0.6293 b	0.2754 b	0.0759 b	1.518 b	0.2755 ab
40	0.3540 a	0.1160 a	1.708 a	0.8881 a	0.3179 a	0.0929 a	1.561 a	0.2894 a
60	0.3060 c	0.1002 bc	1.357 b	0.6182 b	0.2591 b	0.0736 b	1.454 c	0.2648 ab
Sig. level	**	**	**	**	**	**	**	**
$LSD_{(0.05)}$	**0.01**	**0.01**	**0.032**	**0.032**	**0.032**	**0.01**	**0.032**	**0.032**
SX	**0.0029**	**0.0029**	**0.0091**	**0.0091**	**0.0091**	**0.0029**	**0.0091**	**0.0091**
CV (%)	**4.48**	**1.11**	**1.56**	**0.26**	**0.73**	**1.24**	**1.51**	**1.15**

Figures followed by same letter(s) are statistically similar as per DMRT at 5%
LSD= Least significant difference; CV= Co-efficient of variation; **= Significant at 1% level of probability

4.2.2 Main effect of Sulphur

Main effect of Sulphur was also significantly influenced on N, P, K and S content by grain and straw of BRRI dhan57 (Appendix VIII and Table 10). Among the S treatments, the highest N, P, K and S nutrient content by grain (0.3286, 1.565, 0.3477 and 0.818%, respectively) and straw (0.1183, 0.7789, 0.0898 and 0.3234%, respectively) were observed in 20 kg S ha^{-1} while 10 kg S ha^{-1} showed the statistically identical higher N content by grain (0.3282) and S content by straw (0.3100%). However, 30 kg S ha^{-1} also observed the statistically similar higher N content (0.3232%) and K content (0.2422%) by grain. On the other hand, the lowest content of N, P, K and S by grain (0.3109, 1.247, 0.2189 and 1.100%, respectively) and straw (0.0892, 0.5921, 0.0646 and

0.1645%, respectively) were taken in 0 kg S ha^{-1} while it was statistically different from other S levels in this study (Table 10).

Table 10. Main effect of Sulphur on nutrients content by grain and straw

S levels (kg ha^{-1})	N content		P content		K content		S content	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
0	0.3109 b	0.0892 c	1.247 c	0.5921 d	0.2189 c	0.0646 c	1.100 d	0.1645 c
10	0.3282 a	0.1082 b	1.471 b	0.7162 b	0.2875 b	0.0818 ab	1.676 b	0.3100 a
20	0.3286 a	0.1183 a	1.565 a	0.7789 a	0.3477 a	0.0898 a	1.818 a	0.3234 a
30	0.3232 a	0.1034 b	1.457 b	0.6573 c	0.2422 c	0.0751 b	1.349 c	0.2760 b
Sig. level	*	**	**	**	**	**	**	**
$LSD_{(0.05)}$	**0.01**	**0.01**	**0.032**	**0.032**	**0.032**	**0.01**	**0.032**	**0.032**
SX	**0.0029**	**0.0029**	**0.0091**	**0.0091**	**0.0091**	**0.0029**	**0.0091**	**0.0091**
CV (%)	**4.48**	**1.11**	**1.56**	**0.26**	**0.73**	**1.24**	**1.51**	**1.15**

Figures followed by same letter(s) are statistically similar as per DMRT at 5%
LSD= Least significant difference; CV= Co-efficient of variation *= significant at 1% and
**= Significant at 1% level of probability

4.2.3 Interaction effect between Phosphorus and Sulphur

Analysis of variance data regarding to N, P, K and S content by grain and straw of BRRI dhan57 were significantly affected due to interaction effect between Phosphorus and Sulphur in this study (Appendix VIII and Table 11). In case of nutrients content by grain, interaction effect of 40 kg P and 20 kg S ha^{-1} observed the higher contents of N (0.3630%) while interaction of 40 kg P and 10 kg S ha^{-1} obtained the statistically similar higher content of N (0.3570%) and interaction of 40 kg P × 30 kg S ha^{-1} and 40 kg P × 10 kg S ha^{-1} observed the statistically close N content by grain (0.3490 and 0.3463%, respectively). Similarly, 40 kg P × 30 kg S ha^{-1} observed the higher P content by grain (1.874%) which was statistically similar with the interaction of 40 kg P × 20 kg S ha^{-1} (1.844%). Incase of K content by grain, it was higher (0.3663%) in 40 kg P × 20 kg S ha^{-1} while statistically similar higher K content by grain (0.3470 and 0.3413%) was found in 20 kg P × 20 kg S ha^{-1} and 60 kg P × 20 kg S ha^{-1}, respectively which was also statistically close with the interactions of 20 kg P × 10 kg S ha^{-1}, 40 kg P × 10 kg S ha^{-1} and 40 kg P × 30 kg S ha^{-1} (0.3230, 0.3220 and 0.3067%, respectively). S content by grain had also higher (1.883%) in 40 kg P × 20 kg S ha^{-1} which was closely followed by 0 kg P × 20 kg S ha^{-1} (1.833%). In case of nutrients content by straw, N content by straw had higher (0.1280%) in 40 kg P × 20 kg S ha^{-1} which was closely followed by the interactions of 40 kg P × 10 kg S ha^{-1}, 20 kg P × 20 kg S ha^{-1}, 40 kg P × 30 kg S ha^{-1}, 60 kg P × 20 kg S ha^{-1}, 0 kg P × 20 kg S ha^{-1} and 20 kg P × 10 kg S ha^{-1} (0.1227, 0.1213, 0.1173, 0.1140, 0.1100 and 0.1107%, respectively). Similarly, 40 kg P × 20 kg S ha^{-1} further recorded the higher P and K content by straw (1.041 and 0.1070%, respectively) while it was statistically differed from other S levels regarding to P content by straw and 40 kg P × 10 kg S ha^{-1} observed the statistically close S content by straw (0.0937%). S content by straw had also higher (0.3470%) in 40 kg P × 20 kg S ha^{-1} and it was closely followed by the maximum interactions treatment among the whole interactions. All the nutrient content (N, P, K and S) by grain and straw had also lower (0.2927 and 0.0820, 1.137 and 0.548, 0.1910 and 0.0547, and 1.084 and 0.1470%, respectively) in both control fertilizers (0 kg P × 0 kg S ha^{-1}) while 60 kg P × 20 kg S ha^{-1} observed the statistically similar lower N content by grain (0.2940%), 60 kg P × 0 kg S ha^{-1} observed the statistically identical lower P content by grain and K content by grain and straw (0.5590, and 0.2010 and .0583%, respectively) and S content by grain (1.093%). Interaction effect of 20 kg P × 0 kg S ha^{-1} also observed the statistically similar lower K and S content by grain (0.2070 and 1.099%, respectively) while 0 kg P × 30 kg S ha^{-1} and 40 kg P × 0 kg S ha^{-1} further recorded the statistically similar lower S content by grain (1.124 and 1.123%, respectively).

Table 11. Combined effect between Phosphorus and Sulphur on nutrients content by grain and straw

P levels (kg ha^{-1})	S levels (kg ha^{-1})	N content		P content		K content		S content	
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
0		0.293 f	0.082 h	1.13 i	0.55 i	0.191 d	0.054 f	1.08 h	0.147 d
		0.313 de	0.098 d-h	1.38 ef	0.62 f-h	0.232 cd	0.069 c-f	1.59 e	0.298 ab
		0.321 cd	0.110 a-e	1.46 cd	0.68 de	0.336 a	0.083 b-d	1.83 ab	0.312 ab
		0.309 def	0.090 f-h	1.28 g	0.58 g-i	0.217 cd	0.068 d-f	1.12 h	0.220 c
20		0.306 def	0.093 e-h	1.20 h	0.57 hi	0.207 d	0.062 ef	1.09 h	0.171 cd
		0.324 cd	0.111 a-e	1.43 de	0.66 def	0.323 ab	0.082 b-d	1.70 d	0.315 ab
		0.337 bc	0.121 ab	1.49 c	0.69 d	0.347 a	0.085 b-d	1.75 cd	0.318 ab
		0.322 cd	0.107 b-f	1.32 fg	0.59 g-i	0.224 cd	0.073 c-f	1.51 f	0.297 ab
40		0.346 ab	0.096 d-h	1.46 cd	0.69 de	0.276 bc	0.082 b-d	1.12 h	0.178 cd
		0.357 a	0.123 ab	1.66 b	0.95 b	0.322 ab	0.093 ab	1.77 c	0.321 ab
		0.363 a	0.128 a	1.84 a	1.04 a	0.366 a	0.107 a	1.88 a	0.347 a
		0.349 ab	0.117 a-c	1.87 a	0.87 c	0.306 ab	0.088 bc	1.47 f	0.311 ab
60		0.299 ef	0.086 gh	1.19 h	0.56 i	0.201 d	0.058 f	1.09 h	0.162 d
		0.319 cd	0.102 c-g	1.42 de	0.64 e-g	0.273 bc	0.081 b-e	1.63 e	0.305 ab
		0.294 f	0.114 a-d	1.47 cd	0.69 de	0.341 a	0.083 b-d	1.80 bc	0.316 ab
		0.313 de	0.099 c-h	1.35 f	0.58 g-i	0.220 cd	0.071 c-f	1.29 g	0.275 b
Sig. level		*	**	**	**	**	**	**	**
$LSD_{(0.05)}$		**0.017**	**0.017**	**0.053**	**0.053**	**0.053**	**0.017**	**0.053**	**0.053**
SX		**0.0058**	**0.0058**	**0.018**	**0.018**	**0.018**	**0.0058**	**0.018**	**0.018**
CV (%)		**4.48**	**1.11**	**1.56**	**0.26**	**0.73**	**1.24**	**1.51**	**1.15**

Figures followed by same letter(s) are statistically similar as per DMRT at 5%
LSD= Least significant difference; CV= Co-efficient of variation *= significant at 1% and
**= Significant at 1% level of probability

4.3 Responses of Phosphorus and Sulphur on nutrient uptake by grain and straw

4.3.1 Main effect of Phosphorus

Analysis of variance data regarding to Nitrogen (N), Phosphorus (P), Potassium (K) and Sulphur (S) uptake by grain and straw of BRRI dhan 57 were significantly affected due to various Phosphorus levels (Appendix IX and Table 12). The highest N, P, K and S nutrient uptake by grain (16.82, 81.65, 15.27

and 75.63 kg ha^{-1}, respectively) and straw (9.74, 74.54, 7.80 and 24.29 kg ha^{-1}, respectively) were obtained in 40 kg P ha^{-1} while 60 kg P ha^{-1} produced statistically identical lower K uptake by grain (12.44 kg ha^{-1}) and statistically differed from other P levels regarding to rest nutrient uptake. In contrast, the lowest uptake of N, P, K and S by grain (12.27, 52.49, 9.927 and 57.21 kg ha^{-1}, respectively) and straw (6.69, 42.91, 4.85 and 17.21 kg ha^{-1}, respectively) were taken in 0 kg P ha^{-1} while 60 kg P ha^{-1} produced statistically more or less similar lower P uptake by grain (25.92 kg ha^{-1}). Similarly, Khandaker (2003) observed that N, P, K and S uptake by grain were significantly affected by P treated plants. Similar results also noted by Tripathi *et al.* (2001) who also found that the effects of various levels of P on the uptake of P, S, Mn and Fe by rice. They concluded that increasing levels of P significantly enhanced the P, S and Mn uptake whereas it adversely affected Fe uptake and high P level combined with puddling and submergence significantly increased P uptake.

4.3.2 Main effect of Sulphur

Effect of Sulphur was significantly influenced on N, P, K and S uptake by grain and straw of BRRI dhan57 in this study (Appendix IX and Table 13). Among the S treatments, the highest N, P, K and S nutrient uptake by grain (16.88, 80.61, 17.83 and 93.08 kg ha^{-1}, respectively) and straw (9.55, 62.90, 7.25 and 26.11 kg ha^{-1}, respectively) were observed in 20 kg S ha^{-1} while 0 kg S ha^{-1} observed the lowest uptake of N, P, K and S by grain (11.76, 47.22, 8.315 and 41.49 kg ha^{-1}, respectively) and straw (6.40, 42.50, 4.64 and 11.81 kg ha^{-1}, respectively) whereas all the S levels were statistically differed from each other regarding to nutrient uptake by grain and straw in this study (Table 13).

Table 12. Main effect of Phosphorus on nutrients uptake by grain and straw

P levels (kg ha^{-1})	N uptake		P uptake		K uptake		S uptake	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
0	12.27 c	6.69 d	52.49 d	42.66 c	9.927 d	4.85 d	57.21 d	17.21 d
20	14.14 b	8.13 b	60.05 b	47.34 b	12.30 b	5.71 b	67.34 b	20.73 b
40	16.82 a	9.74 a	81.65 a	74.54 a	15.27 a	7.80 a	75.63 a	24.29 a
60	12.44 c	7.31 c	55.65 c	45.09 c	10.80 c	5.37 c	60.36 c	19.31 c
Sig. level	**	**	**	**	**	**	**	**
LSD$_{(0.05)}$	**0.738**	**0.141**	**0.7757**	**2.364**	**0.141**	**0.045**	**1.407**	**0.253**
SX	**0.2133**	**0.0408**	**0.2242**	**0.683**	**0.0408**	**0.0129**	**0.4065**	**0.073**
CV (%)	**5.09**	**1.34**	**1.66**	**2.64**	**1.29**	**1.43**	**1.79**	**1.28**

Figures followed by same letter(s) are statistically similar as per DMRT at 5% LSD= Least significant difference; CV= Co–efficient of variation; **= Significant at 1% level of probability

Table 13. Main effect of Sulphur on nutrients uptake by grain and straw

S levels (kg ha^{-1})	N uptake		P uptake		K uptake		S uptake	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
0	11.76 d	6.40 d	47.22 d	42.50 d	8.315 d	4.64 d	41.49 d	11.81 d
10	14.00 b	8.35 b	62.88 b	55.24 b	12.33 b	6.31 b	71.42 b	23.91 b
20	16.88 a	9.55 a	80.61 a	62.90 a	17.83 a	7.25 a	93.08 a	26.11 a
30	13.02 c	7.54 c	59.13 c	47.94 c	9.826 c	5.48 c	54.55 c	20.13 c
Sig. level	**	**	**	**	**	**	**	**
LSD$_{(0.05)}$	**0.596**	**0.053**	**1.036**	**0.564**	**0.131**	**0.038**	**0.98**	**0.128**
SX	**0.2043**	**0.0183**	**0.2993**	**0.1932**	**0.0447**	**0.0129**	**0.3357**	**0.0438**
CV (%)	**5.09**	**1.34**	**1.66**	**2.64**	**1.29**	**1.43**	**1.79**	**1.28**

Figures followed by same letter(s) are statistically similar as per DMRT at 5% LSD= Least significant difference; CV= Co–efficient of variation, **= Significant at 1% level of probability

Table 14. Combined effect between Phosphorus and Sulphur on nutrients uptake by grain and straw

P levels (kg ha^{-1})	S levels (kg ha^{-1})	N content		P content		K content		S content	
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
0		10.24 i	5.51 n	39.77 n	36.81 n	6.680 m	3.67 m	37.93 k	9.87 n
		12.14 fg	7.09 j	53.40 j	44.96 i	8.983 i	5.06 j	61.96 g	21.61 h
		15.29 c	8.13 e	69.49 f	50.75 f	16.03 d	6.13 e	87.46 c	23.05 d
		11.41 ghi	6.17 l	47.29 l	39.70 l	8.017 k	4.65 k	41.50 j	15.03 j
20		11.97 fgh	6.60 k	47.11 l	40.36 k	8.107 k	4.45 k	43.02 j	12.13 l
		13.90 de	8.45 f	61.41 g	50.29 g	13.87 f	6.28 f	73.38 e	24.06 f
		17.46 b	9.90 b	77.28 d	56.96 d	18.00 b	6.99 c	90.84 b	26.01 b
		13.22 def	7.72 g	54.39 j	42.61 h	9.233 i	5.26 i	62.11 g	21.41 g
40		14.04 d	7.66 i	59.04 h	55.24 h	11.22 g	6.60 g	45.55 i	14.21 k
		17.25 b	10.46 c	80.20 c	80.88 b	15.55 e	7.99 b	85.35 d	27.36 c
		20.45 a	11.48 a	103.9 a	93.35 a	20.64 a	9.60 a	106.1 a	31.12 a
		15.55 c	9.50 e	83.49 b	70.47 c	13.66 f	7.15 e	65.50 f	25.25 e
60		10.79 hi	5.92 m	42.96 m	38.64 m	7.257 l	4.03 l	39.45 k	11.20 m
		12.72 efg	7.60 h	56.51 i	47.44 h	10.91 h	6.05 h	65.01 f	22.77 g
		14.32 cd	8.88 d	71.76 e	53.731 e	16.66 c	6.52 d	87.92 c	24.61 c
		11.92 fgh	6.96 j	51.37 k	41.27 j	8.393 j	4.99 j	49.08 h	19.35 i
Sig. level		**	**	**	**	**	**	**	**
$LSD_{(0.05)}$		**1.193**	**0.107**	**1.747**	**1.128**	**0.261**	**0.075**	**1.959**	**0.256**
SX		**0.4087**	**0.0365**	**0.5986**	**0.3864**	**0.0894**	**0.0258**	**0.6713**	**0.0876**
CV (%)		**5.09**	**1.34**	**1.66**	**2.64**	**1.29**	**1.43**	**1.79**	**1.28**

Figures followed by same letter(s) are statistically similar as per DMRT at 5% LSD= Least significant difference; CV= Co–efficient of variation, **= Significant at 1% level of probability

4.3.3 Interaction effect between Phosphorus and Sulphur

A significant variation was also observed due to the interaction effect between Phosphorus and Sulphur in this study regarding to N, P, K and S uptake by grain and straw (Appendix IX and Table 14). In case of nutrients content by grain, interaction effect of 40 kg P and 20 kg S ha^{-1} observed the higher uptake of N, P, K and S (20.45, 103.90, 20.64 and 106.10 kg ha^{-1}, respectively) while it was statistically differed from another interactions. Similarly, similar interaction treatment also recorded the higher uptake of N, P, K and S by straw (11.48, 73.35, 9.60 and 31.12 kg ha^{-1}, respectively). On the other hand, the lowest uptake of N, P, K and S by grain and straw had lower (10.24 and 5.51, 39.77 and 36.81, 6.680 and 3.67, and 37.93 and 9.87 kg ha^{-1}, respectively) in interaction of 0 kg P and 0 kg S ha^{-1} while statistically similar lower S uptake by grain (39.45 kg ha^{-1}) was observed in 60 kg P and 0 kg S ha^{-1} (Table 14).

Above results indicated that the P @ 40 kg ha^{-1} and S @ 20 kg ha^{-1} singly or their interaction showed the superior performance for obtaining the greater field performance and better nutrient quantity of the studied rice cultivar cv. BRRI dhan 57. Tallest plant, maximum total and effective tillers, maximum filled grain, longest panicle, highest yield of grain, straw and biological and higher HI as well as the maximum nutrient content and uptake were perform by the single or interaction treatment of 40 kg P ha^{-1} and 20 kg S ha^{-1} compare to that of other studied treatments whereas control treatment always showed the least performance among the studied all traits. Finally, it could be concluded that the use of 40 kg P ha^{-1} or 20 kg S $ha^{-1}$of as soil application would be highly effective for higher production of BRRI dhan57 as well as to get higher nutrient content and uptake by grain and straw.

Chapter V

Summary and conclusion

CHAPTER 5
SUMMARY AND CONCLUSION

The present study was conducted at the Research Field of the Department of Soil Science, Sher-e-Bangla Agricultural University (SAU), Sher-e-Bangla Nagar, Dhaka-1207 during the period from July 2013 to December 2013 to evaluation on the performance of BRRI dhan57 in respect of morpho–physiology and yield under the AEZ-28. The rice variety cv. BRRI dhan57 was used as planting materials for the present study which was collected from BRRI, Joydebpur, Gazipur. The two factors experiment consists with four levels of Phosphorus (P) *viz.* P_0: without Phosphorus (control), P_1: 20 kg ha^{-1}, P_2: 40 kg ha^{-1} and P_3: 60 kg ha^{-1} and four levels of Sulphur *viz.* S_0: without Sulphur (control), S_1: 10 kg ha^{-1}, S_2: 20 kg ha^{-1} and S_3: 30 kg ha^{-1}. The experiment was laid out in Randomized Completely Block Design (RCBD) method with three replications and analysis was done by the MSTAT-C package program whereas means were adjudged by DMRT at 5% level of probability.

The results of the present study were obtained on various characteristics of morpho–physiology, yield and yield attributing traits of BRRI dhan57 whereas all the studied characters were statistically significant at 5% level due to phosphorus application where 40 kg P ha^{-1} showed superior performance on them. The result of plant height and tillers $hill^{-1}$ were significantly increase with the advancement of study period while tillers production significantly decreased at harvest due to its mortality for maturity. As a result, the tallest plant (109.70 cm) was found in 40 kg P ha^{-1} while without phosphorus recorded the shortest plant (106.20 cm) at harvest. Similarly, maximum tillers $hill^{-1}$ (17.58) was attaining in 40 kg P ha^{-1} and control P obtained the minimum tillers $hill^{-1}$ (13.63) at 85 DAT thereafter it decreased at harvest. Phosphorus @ 40 kg ha^{-1} also recorded the greater results on effective tillers $hill^{-1}$ (13.67), panicle length (22.04 cm), filled grains $panicle^{-1}$ (138.60), 1000-grain weight

(30.75 g), weight of grain, straw and biological (5.12, 8.39 and 13.51 t ha^{-1}, respectively) and harvest index (37.85%) at harvest while without phosphorus obtained the lower results on the above traits (7.98, 19.33 cm, 110.0, 26.36 g, 3.77 t ha^{-1}, 7.05 t ha^{-1}, 10.81 t ha^{-1} and 34.82%, respectively) whereas all the treatments of P were statistically differed with each other. However, 40 kg P ha^{-1} noticed the minimum non effective tillers $hill^{-1}$ (2.33) and unfilled grains $panicle^{-1}$ (8.45) and control treatment obtained the maximum non effective tillers $hill^{-1}$ (3.85) and unfilled grains $panicle^{-1}$ (15.93).

Maximum studied characters of the previously indicated were also significantly influenced by Sulphur application. However, plant height at 55, 85 DAT and at harvest, filled grains $panicle^{-1}$ and 1000-grain weight did not vary significant due to the effect of S. The data on plant height and tillers $hill^{-1}$ were recorded at 30 days interval from 25 DAT to 85 DAT and at harvest where plant height increased up to harvest and tiller production at 85 DAT and decreased at harvest due to mortality. However, plant height at harvest was statistically identical among the S levels but 20 kg S ha^{-1} obtained the tallest plant (109.40 cm) at harvest while control S recorded the shortest plant (106.70 cm) at harvest. Maximum tillers $hill^{-1}$ (16.28) was also observed in 20 kg S ha^{-1} and minimum tillers $hill^{-1}$ (14.63) in control S at 85 DAT while it decreased at harvest. On the other hand, the maximum effective tillers $hill^{-1}$ (12.12), longest panicle (21.35), higher weight of grain, straw and biological (4.75, 8.08 and 12.82 t ha^{-1}, respectively) and harvest index (36.90%) were taken in 20 kg S ha^{-1} at harvest. Similarly, control S recorded the minimum effective tillers $hill^{-1}$ (9.37), shortest panicle (19.96 cm), minimum yield of grain, straw and biological (3.96, 7.18 and 11.14 t ha^{-1}, respectively) and lowest HI (35.45%) whereas statistically similar lower effective tillers $hill^{-1}$ (9.47), shortest panicle (20.19 cm), lowest yield of grain, straw and biological (4.07, 7.29 and 11.36 t ha^{-1}, respectively) and lowest HI (35.71%) were also found in higher doses of S (30 kg S ha^{-1}). However, 20 kg S ha^{-1} observed the minimum non effective tillers $hill^{-1}$ (2.83) and unfilled grains $panicle^{-1}$ (12.04) but maximum non effective tillers hill (3.38) and unfilled grains panicle^{-1} (13.42) were taken in 30 kg S ha^{-1} and 10 kg S ha^{-1}, respectively while all the S levels including control were produced statistically similar filled grains panicle^{-1} and 1000-grain weight at harvest due to non significant variation.

All the studied characters among the morpho–physiology, yield and yield contributing were significantly affected by the interaction effect between Phosphorus and Sulphur fertilizers at all the growth stages and at harvest whereas interactions affect between 40 kg P and 20 kg S ha^{-1} perform the best comparatively than that of other interactions. However, tiller production hill^{-1} increased with the advancement of DAT but it decreased at harvest. As a result, the tillers production had more at 85 DAT whereas the maximum tillers hill^{-1} (18.10) was obtained in 40 kg P + 20 kg S ha^{-1} while minimum tillers hill^{-1} (13.00) was found in both control fertilizers which was statistically identical with 0 kg P + 30 kg S ha^{-1} (13.10). Plant height had also higher (111.60 cm) in 40 kg P + 20 kg S ha^{-1} and lower (105.40 cm) in control at harvest whereas statistically similar lower height (105.90 and 105.50 cm) was also found in interactions of 0 kg P + 10 kg S ha^{-1} and 0 kg P + 30 kg S ha^{-1}, respectively. The interaction treatment of 40 kg P + 20 kg S ha^{-1} also produced maximum effective (15.53) and minimum non effective tillers hill^{-1} (1.97), longest panicle (23.26 cm), maximum filled (141.40) and minimum unfilled grains panicle^{-1} (7.87), highest weight of 1000 grain (31.63 g), higher yield of grain, straw and biological (5.64, 8.97 and 14.60 t ha^{-1}) and higher HI (38.59%) whereas they were statistically significant among other interactions in respect of all the above traits. However, interaction of both control recorded the minimum effective tillers hill^{-1} (7.17), shortest panicle (18.70 cm), minimum filled grains panicle^{-1} (108.80), lowest weight of 1000-grain (25.88 g), lowest yield of grain, straw and biological (3.50, 6.72 and10.21 t ha^{-1})and lowest HI (34.24%) but it was statistically identical filled grains panicle^{-1} (109.40 and 108.90) were obtained by the interactions of 0 kg P + 10 kg S ha^{-1} and 0 kg P + 30 kg S ha^{-1}, respectively. Number of non effective tillers hill^{-1} and unfilled grains panicle^{-1}

had maximum (3.97 and 16.27, respectively) in 0 kg P + 30 kg S ha^{-1} and 0 kg P + 10 kg S ha^{-1}, respectively at harvest which was statistically differed from other interactions.

From the above results, it could be concluded that P @ 40 kg ha^{-1} and S @ 20 kg ha^{-1} singly or their interaction showed the superior performance concerning to morpho–physiology, yield and yield traits of BRRI dhan57 in this study. As a result, tallest plant, maximum total and effective tillers, maximum filled grain, longest panicle, higher yield of grain, straw and biological as well as higher HI were taken by the single or interaction of 40 kg P ha^{-1} and 20 kg S ha^{-1} compare to that of other studied treatments whereas control treatment always showed the least performance among the maximum studied characters. Finally, it could be concluded that the use of 40 kg P ha^{-1} or 20 kg S ha^{-1} as singly or their interaction would be highly effective for higher production of BRRI dhan57 under the regional condition of AEZ–28. So, it can be recommended that 40 kg P ha^{-1} or 20 kg S ha^{-1} fertilizer would be optimum level for getting the higher production of BRRI dhan57. Further study may be needed for ensuring the performance of the present study in different AEZ of Bangladesh.

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Appendices

APPENDICES

Appendix I. The morphological, physical and chemical properties of the experimental land

Morphological characteristics

Constituents	Characteristics
Location	Field Laboratory, Department of Soil Science, SAU, Dhaka
Soil Series	Tejgaon
Soil Tract	Modhupur
Land type	High
General soil type	Deep Red Brown Terrace Soil
Agro-Ecological Zone	"AEZ-28"
Topography	Fairly level
Soil type and colour	Deep Red Brown Terrace Soil
Drainage	Moderate
Depth of inundation	Above the flood level
Drainage condition	Well drained

Physical properties of the soil

Constituents	Results
Particle size analysis	2.57
Bulk density (g/cc)	1.42
Porosity (%)	44.7
Sand (%) (>0.02 mm)	21.75
Silt (1%) (0.02-0.002 mm)	66.60
Clay (%) (<0.002 mm)	11.65
Soil textural class	Silty loam
Color	Dark grey
Consistency	Grounder

Result obtained from the mechanical analysis of the initial soil sample done in the Soil Resources Development Institute (SRDI), Dhaka.

Chemical composition of the initial soil (0-15 cm depth)

Constituents	Results
Soil pH	5.8
Organic matter (%)	1.30
Total nitrogen (%)	0.101
Available phosphorus (ppm)	27
Exchangeable potassium (meq/100 g soil)	0.12
Available Sulphur (ppm)	22.7

Methods of analysis

Texture	Hydrometer methods
pH	Ptentiometric method
Organic carbon	Walkely-Black method
Total N	Modified kjeldhal method
Available P	Olsen method ($NAHCO^3$)
Exchangeable K	Flame photometer method
Available S	Spectrophotometer methods (0.15% $CaCl_2$ solution)

Result obtained from the chemical analysis of the initial soil sample done in the Soil Resources Development Institute (SRDI), Dhaka.

Appendix II. Monthly air temperature, rainfall, relative humidity and sunshine hours during the growing season (July to December 2013)

Month	Year	*Air temperature (^{0}C)			**Rainfall (mm)	*Relative humidity (%)	** Sunshine (hrs)
		Maximum	Minimum	Average			
July	2013	28.77	15.33	22.05	0	73.57	223.40
August	2013	30.93	18.95	24.94	18.1	75.16	202.10
September	2013	28.53	16.85	22.69	19.58	79.58	119.65
October	2013	27.15	15.99	21.57	23.21	81.62	101.41
November	2013	26.54	14.61	20.58	21.54	82.35	111.26
December	2013	24.92	13.46	19.19	0	86.16	160.40
Average							

* Monthly average and ** Monthly total

Source: Bangladesh Meteorological Department (Climate division), Dhaka.

Appendix III: Lay out of the experiment

$P_0 \times S_0 \times R_1$	$P_0 \times S_0 \times R_2$	$P_0 \times S_0 \times R_3$
$P_0 \times S_1 \times R_1$	$P_0 \times S_1 \times R_2$	$P_0 \times S_1 \times R_3$
$P_0 \times S_2 \times R_1$	$P_0 \times S_2 \times R_2$	$P_0 \times S_2 \times R_3$
$P_0 \times S_3 \times R_1$	$P_0 \times S_3 \times R_2$	$P_0 \times S_3 \times R_3$
$P_1 \times S_0 \times R_1$	$P_1 \times S_0 \times R_2$	$P_1 \times S_0 \times R_3$
$P_1 \times S_1 \times R_1$	$P_1 \times S_1 \times R_2$	$P_1 \times S_1 \times R_3$
$P_1 \times S_2 \times R_1$	$P_1 \times S_2 \times R_2$	$P_1 \times S_2 \times R_3$
$P_1 \times S_3 \times R_1$	$P_1 \times S_3 \times R_2$	$P_1 \times S_3 \times R_3$
$P_2 \times S_0 \times R_1$	$P_2 \times S_0 \times R_2$	$P_2 \times S_0 \times R_3$
$P_2 \times S_1 \times R_1$	$P_2 \times S_1 \times R_2$	$P_2 \times S_1 \times R_3$
$P_2 \times S_2 \times R_1$	$P_2 \times S_2 \times R_2$	$P_2 \times S_2 \times R_3$
$P_2 \times S_3 \times R_1$	$P_2 \times S_3 \times R_2$	$P_2 \times S_3 \times R_3$
$P_3 \times S_0 \times R_1$	$P_3 \times S_0 \times R_2$	$P_3 \times S_0 \times R_3$
$P_3 \times S_1 \times R_1$	$P_3 \times S_1 \times R_2$	$P_3 \times S_1 \times R_3$
$P_3 \times S_2 \times R_1$	$P_3 \times S_2 \times R_2$	$P_3 \times S_2 \times R_3$
$P_3 \times S_3 \times R_1$	$P_3 \times S_3 \times R_2$	$P_3 \times S_3 \times R_3$

Legend:

Treatments: 16 (P: 4 × S: 4); Replication: 3 (Three); Number of plot: 48
Length of plot: 4.0 m; Width of a plot: 3.0 m; Area of a plot: 12.0 m^2
Row to row distance: 0.20 m; plant to plant distance: 0.20 cm

Appendix IV. Analysis of variance (mean square) for plant height of BRR dhan 57 at different days after transplanting

Source of variation	Degrees of freedom	Plant height (cm)at different DAT			
		25	55	85	Harvest
Replication	2	7.286	31.313	78.505	83.208
Phosphorus (A)	3	12.245**	102.31**	28.09**	27.872**
Error	6	0.53	12.557	44.297	22.498
Sulphur (B)	3	15.92**	11.512ns	18.581ns	19.405ns
A×B	9	0.001*	0.001*	0.021*	0.001*
Error	24	0.099	0.247	0.665	1.162

Appendix V. Analysis of variance (mean square) for number of total tillers hill^{-1} of BRRI dhan 57 at different days after transplanting

Source of variation	Degrees of freedom	No. of tillers hill^{-1} at different DAT			
		30	60	90	
Replication	2	0.122	6.098	1.523	1.251
Phosphorus (A)	3	0.571**	38.707**	34.388**	38.707**
Error	6	0.05	1.243	0.177	0.073
Sulphur (B)	3	7.467**	13.257**	6.867**	13.257**
A×B	9	0.000ns	0.000ns	0.187*	0.000ns
Error	24	0.017	0.249	0.2	0.007

**= Significant at 1% and *= Significant at 5% level of probability and ns= not significant

Appendix VI. Analysis of variance (mean square) for tiller production (no.), panicle length and grain production (no.) at harvest

Source of variation	Degrees of freedom	No. of non effective tillers hill^{-1}	No. of effective tillers hill^{-1}	Panicle length (cm)	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}
Replication	2	1.063	0.056	9.1	393.547	7.472
Phosphorus (A)	3	70.915**	4.886**	15.576**	1784.197**	121.404**
Error	6	0.104	0.006	0.921	65.631	1.674
Sulphur (B)	3	19.673**	0.721**	4.427*	156.657ns	4.367*
A×B	9	0.031*	0.031**	0.125**	13.205**	0.395**
Error	24	0.011	0.001	0.01	1.373	0.087

Appendix VII. Analysis of variance (mean square) for different yield and yield contributing characters of rice cv. BRRI dhan57

Source of variation	Degrees of freedom	1000–grain weight	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	15.118	0.189	0.771	7.877	20.901
Phosphorus (A)	3	40.225**	4.131**	4.117**	16.55**	20.29**
Error	6	5.733	0.034	0.078	1.877	0.708
Sulphur (B)	3	5.671ns	1.494**	2.027**	6.957*	4.827*
A×B	9	0.059*	0.022**	0.022*	0.088*	0.083*
Error	24	0.37	0.005	0.009	0.098	0.723

**= Significant at 1% and *= Significant at 5% level of probability and ns= not significant

Appendix VIII. Analysis of variance (mean square) for different nutrient content by grain and straw of BRRI dhan57

Source of variation	Degrees of freedom	N content (%)		P content (%)		K content (%)		S content (%)	
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Replication	2	0.001	0.001	0.038	0.002	0.001	0.000	0.024	0.001
Phosphorus	3	0.006**	0.001**	0.405**	0.218**	0.012**	0.001**	0.054**	0.004**
Error	6	0.001	0.0001	0.001	0.001	0.001	0.0001	0.001	0.001
Sulphur	3	0.002*	0.002**	0.217**	0.077**	0.039**	0.001**	1.255**	0.062**
AB	9	0.001*	0.001**	0.015**	0.007**	0.001**	0.001**	0.023**	0.001**
Error	24	0.0001	0.0001	0.001	0.001	0.001	0.0001	0.001	0.001

**= Significant at 1% and *= Significant at 5% level of probability and ns= not significant

Appendix IX. Analysis of variance (mean square) for different yield and yield contributing characters of rice cv. BRRI dhan57

Source of variation	Degrees of freedom	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})		S uptake (kg ha^{-1})	
		Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Replication	2	0.661	0.679	154.625	64.788	3.908	0.215	119.489	4.468
Phosphorus	3	53.575**	7.235**	2080.15**	1866.43**	65.868**	6.615**	801.884**	37.493**
Error	6	0.546	0.020	0.603	5.598	0.020	0.002	1.983	0.064
Sulphur	3	57.013**	15.447**	2291.45**	1697.98**	209.559**	10.187**	5967.91**	225.61**
AB	9	1.001**	0.160**	45.644**	98.206**	1.755**	0.098**	57.543**	1.792**
Error	24	0.501	0.004	1.075	0.448	0.024	0.002	1.352	0.023

**= Significant at 1% and *= Significant at 5% level of probability and ns= not significant