EFFECT OF NITROGEN AND SULPHUR ON YIELD AND YIELD COMPONENTS OF RAPESEED

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CERTIFICATE

*This is to certify that the thesis entitled, " **EFFECT OF NITROGEN AND SULPHUR ON YIELD AND YIELD COMPONENTS OF RAPESEED”** submitted to the DEPARTMENT OF AGRONOMY**, Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka** in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE** in **AGRONOMY** embodies the result of a piece of bona fide research work carried out by **RAFIQUL ISLAM, Reg. No. 10-04034** 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.

Dated:

Dhaka, Bangladesh

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The Author

EFFECT OF NITROGEN AND SULPHUR ON YIELD AND YIELD COMPONENTS OF RAPESEED

ABSTRACT

A field experiment was conducted to evaluate the effect of nitrogen (N) and sulphur (S) on yield and yield components of rapeseed (BARI Sarisha-14) at Sher-e-Bangla Agricultural University Farm, Dhaka-1207 during November, 2015 to February, 2016. The experiment was consisted of four levels of nitrogen *viz.*, N_0 = 0 kg ha^{-1} (control), N_1 = 60 kg ha^{-1}, N_2 = 120 kg ha^{-1}, N_3 = 180 kg ha^{-1}; and four levels of sulphur *i.e.*, S_0 = 0 kg ha^{-1} (control), S_1 = 15 kg ha^{-1}, S_2 = 30 kg ha^{-1}, S_3 = 45 kg ha^{-1}. Levels of N and S showed significant effect on yield and yield contributing characters of BARI Sarisha-14. Results showed that application of 120 kg N ha^{-1} with 45 kg S ha^{-1} gave the maximum yield. Results also revealed that the highest plant height, number of branches $plant^{-1}$, number of siliquae $plant^{-1}$, siliqua length, number of seeds $siliqua^{-1}$, 1000-seed weight, seed yield, stover yield, biological yield and harvest index were obtained from the combination of 120 kg N with 45 kg S ha^{-1}.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEZ	Agro-Ecological Zone
Agric.	Agriculture
Agril.	Agricultural
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
cm	Centi-meter
CV	Coefficient of Variance
cv.	Cultivar
DAS	Days after sowing
df	Degrees of freedom
Environ.	Environmental
et al.	And others
etc.	Etcetra
g	Gram (s)
HI	Harvest index
i.e.	*id est* (L), that is
J.	Journal
kg	Kilogram (s)
LSD	Least Significant Difference
m^2	Meter squares
M.S	Master of Science
pod^{-1}	Per pod
Res.	Research
SAU	Sher-e-Bangla Agricultural University
Sci.	Science
SRDI	Soil Resource Development Institute
t ha^{-1}	Ton per hectare
viz.	Namely
%	Percentage
^oC	Degree centigrade
@	At the rate of

Chapter 1

Introduction

CHAPTER I

INTRODUCTION

Rapeseed (*Brassica spp.*) belonging to the family Brassicaceae are important sources of edible vegetable oil and currently ranks as the world third most oil crops after palm and soybean in terms of production and area (Adnan *et al.,* 2013; Zhang and Zhou, 2006). It has remarkable demand as edible oil in Bangladesh. Rapeseed tops the list among the oilseed crops grown in this country in respect of both production and acreage (BBS, 2015). Rapeseed is a rich source of energy (about 9 kcal g^{-1}) and fat soluble vitamins like A, D, E and K. On the nutritional point of view at least 15-20 % calories should come from the fats and oils in human diet. In Bangladesh, annual production of edible oilseed is 0.3 million tons. Rapeseed-mustard covers 67 % of total oil seed cropped area of Bangladesh and produces about 56 % of the total oil seed requirement (BBS, 2015). But it does not fulfill the necessity of the country. As a result, huge amount of foreign exchange is being spent every year for importing edible oils. With the increasing growth rate of population, the demand of edible oil is increasing day by day. Therefore, it is highly accepted that the production of edible oil should be increased considerably to fulfill the demand.

Since last few decades, the growth, development, and productivity of *Brassica* have been hampered due to a number of factors including the unbalanced plant mineral nutrients in soils. The application of nitrogen (N) has been a critical element for plant growth, and plant response to added N has proven to be a valuable agronomic practice since time immemorial. The N supply of oilseed rapeseed is of central importance to ensure high yields. As rapeseed are heavy users of N, and available N is the most limiting source in many areas of the world (Kessel, 2000; Rossato *et al.,* 2001), therefore, mineral N fertilization is a crucial factor in oilseed rapeseed production (Dreccer, 2000; Rathke and Schuster, 2001;

Abdallah *et al.,* 2010), and because of low harvest index of rapeseed, high rates of N fertilizer are usually applied to this crop in order to seed yield maximization in diverse and contradicting conditions (Behrens *et al.,* 2002; Behrens, 2002; Rathke *et al.,* 2006). However, fertilizer N requirements can differ very much according to soil type, climate, management practice, timing, source, and rate of N application, cultivars, and so forth (Ali *et al.,* 1998). Many studies have shown that both growth and yield of rapeseed are enhanced significantly by high doses of applied N (Cheema *et al.,* 2001; Kumar *et al.,* 2001). Nitrogen increases yield by influencing a number of growth parameters such as number of branches and siliquae plant^{-1}, seeds siliqua^{-1} and 1000-seed weight by producing more vigorous growth and development (Taylor *et al.,* 1991; Qayyum *et al.,* 1998). Excess N, however, can reduce seed yield and quality appreciably (Cheema *et al.,* 2001; Laaniste *et al.,* 2004).

The deficiency of soil S in the agricultural soils has been reported frequently over the past several years (Scherer, 2001; Ahmad *et al.,* 2005a, b). Most of the Bangladesh soils are also deficient in S due to extensive use of S free fertilizers and intensive crop production. Continuous mining of S from soils has led to widespread S deficiency and negative soil budget (Aulakh, 2003). Sulphur (S) is one of the six macronutrients needed for proper plant development. The S requirement by plants varies with the developmental stage and with species whereas its concentration in plants varies between 0.1 and 1.5% of dry weight. It is pertinent to mention here that *Brassica* have greater S requirements than other large crop species such as wheat or maize and, therefore, are particularly sensitive to S deficiency because of their high demand for S (Ahmad and Abdin, 2000; Walker and Booth, 2003; Anjum *et al.,* 2011). For example, the production of 1 ton of rapeseed seeds requires 16 kg of S (Blake-Kalff *et al.,* 2001), compared with 2-3 kg for each ton of grain in *Triticum aestivum* (Zhao *et al.,* 1996). Hence, S deficiency also causes a reduction in the quality and quantity of rapeseed yield by 40 % (Scherer, 2001; De Pascale *et al.,* 2008; Abdallah *et al.,* 2010; D'Hooghe *et al.,* 2013)

Moreover, S requirement and metabolism in plants including rapeseed are closely related to N nutrition, and N metabolism is also strongly affected by the S status of the plant (Fazili *et al.,* 2008). The assimilatory pathways of S and N have been considered functionally convergent and well coordinated as the availability of one element regulates the other (Reuveny *et al.,* 1980; Schnug *et al.,* 1993) and that C assimilation pathway is closely linked to nitrate assimilation in plants (Ahmad and Abdin, 2000). Moreover, Fismes *et al.* (2000) have shown using field-grown oilseed rapeseed that S deficiency can reduce nitrogen use efficiency (NUE: ratio of harvested N to N fertilization) and that N deficiency can also reduce sulphur use efficiency (SUE). Additionally, positive interaction between S and N has been reported to be beneficial for various aspects of oilseed rapeseed including tolerance to various stress factors.

Therefore, balancing N and S fertilization and the coordination in action between S and N could be a significant strategy for improvement of growth and productivity of rapeseed. Under these circumstances the present research work was undertaken with a view to evaluate the significance of N and S for the improvement of yield and yield contributing characters of BARI Sarisha-14 with the following objectives:

i. to examine the effect of N and S on the yield performances of rapeseed,
ii. to investigate the combined effect of N and S on the yield and yield components of rapeseed.

Chapter 2
Review of literature

CHAPTER II

REVIEW OF LITERATURE

Cruciferous *Brassica* is one of the common and most important oil crops of Bangladesh and as well as many countries of the world. In Bangladesh the average productivity of rapeseed is low in comparison to the developed countries. The crop has received much attention by the researchers on various aspects of its production. Many studies have been carried out in many countries of the world. Nevertheless, some of the important and informative works and research findings about application of nitrogen and/or sulphur in rapeseed have been reviewed in this chapter.

2.1 Effect of nitrogen on yield and yield components of rapeseed

Ma and Herath (2016) conducted a field experiment for 3 years in Ontario, Canada to determine the impact of different rates and timing of application of N fertilizer on canola yield. Side-dressed N application resulted in significant improvements in seed yield. The highest seed yield (2700 kg ha^{-1} in 2011 and 3500 kg ha^{-1} in 2013) was produced by the treatments including side-dressing: 50 + 50 kg N ha^{-1} or 50 + 100 kg N ha^{-1} (preplant + side-dressing). Mehmet *et al.* (2016) found that branch number, siliquae number $plant^{-1}$, seed number $siliquae^{-1}$, seed yield $plant^{-1}$, 1000-seed weight and seed yield increased as N doses increased.

Al-Solaimani *et al.* (2015) carried out an experiment to determine the effect of different rates of N fertilizer (0, 60, 120 and 180 kg N ha^{-1}) on crop growth, seed yield, yield components and seed quality. Statistical analysis of the obtained data presented that N at a rate of 180 kg N ha^{-1} dominated other N rates of 120, 60, 0 kg N ha^{-1} for plant growth, yield and quality parameters. An overall improvement of 59 % in plant height, 112% in number of branches, 111 % in number of siliquae $plant^{-1}$, 87 % in 1000-seed weights were documented for 180 Kg N ha^{-1}. Current results suggested that N at a rate of 180 Kg ha^{-1} can be adopted as best level of N fertilizer for canola cultivation. Rimi *et al.* (2015) found that N significantly increased number of siliquae $plant^{-1}$ and 1000-seed weight up to 120 kg N ha^{-1} but the highest dose 180 kg N ha^{-1} failed to produce better results as other doses.

Keivanrad and Zandi (2014) investigated the agronomical and qualitative features of Indian mustard in a semi-arid region from Iran. The all growth and yield parameters (plant height, number of seeds $siliquae^{-1}$, the number of siliquae $plant^{-1}$, seed yield, biological yield, 1000-seed weight and harvest index) of mustard plant were significantly affected by N fertilization. The highest seed yield (2961 kg ha^{-1}) was obtained for the crop utilized with 200 kg N ha^{-1}. Mansoori (2012) studied the effect of N and S on yield and yield components of canola (*Brassica napus* L). The results indicated the significant influence of N on plant height, number of siliquae $plant^{-1}$, number of seeds $siliquae^{-1}$, 1000-seed weight and seed yield.

Mozaffari *et al.* (2012) carried out a field experiment to assessed the effect of different levels of nitrogen (N_0, N_{75}, N_{150} and N_{225} kg ha^{-1}) on yield and some of the agronomical characteristics in mustard. The results showed that increased amount of N up to 225 kg N ha^{-1} had a positive and significant on seed yield of mustard. However, increased levels of nitrogen had a significant effect on harvest index but showed no consistent trend. The maximum and minimum of harvest index were recorded in the treatments N_{225} and N_{75} kg ha^{-1}. Moreover the results indicate that the interaction effect of N on all of the characters being studied was significant ($p<0.01$).

Öztürk (2010) indicated that 100 and 150 kg N ha^{-1} rate increased significantly yield and quality traits with regard to other N treatments. Kovács *et al.* (2009) showed that application of N in yellow mustard increased seed yield. A field experiment was conducted by Patel *et al.* (2004) to investigate the effects of irrigation schedule, spacing (30 and 40 cm) and N rates (50, 75 and 100 kg ha^{-1})

on the growth, yield and quality of Indian mustard cv. GM-2. In combination treatments, 3 irrigation + N at 100 kg ha^{-1} + spacing of 45 cm resulted in a significant increase in yield. Growth, yield attributes and seed yield increased with increasing N levels.

A field experiment was conducted by Sinsinwar *et al.* (2004) to determine the best cropping sequence and N fertilizer application rate (0, 30, 60 and 90 kg ha^{-1}) of Indian mustard cv. RH-30 under brackish water situation. The cropping sequences did not affect the growth, yield and yield components (*i.e.* plant height, number of primary and secondary branches $plant^{-1}$, number of siliquae $plant^{-1}$), 1000-seed weight and seed yield in both years. The seed yield of Indian mustard significantly increased with each increment of N fertilizer up to 60 kg ha^{-1}, beyond which the increase was marginal. On an average, the increase in seed yield compared to the control was 33.3 and 83.8 % with 30 and 60 kg N ha^{-1}, respectively.

Singh *et al.* (2004) reported that nitrogen application did not affect the oil content in mustard but oil yield and chlorophyll content were increased up to 90 kg N ha^{-1} over the control. Nitrogen application increased the seed yield of mustard. Prasad *et al.* (2003) stated that N at 30 kg ha^{-1} + P at 20 kg ha^{-1} + Zn at 5 kg ha^{-1}, and N at 60 kg ha^{-1} + P at 30 kg ha^{-1} + S at 20 kg ha^{-1} produced the highest growth, yield and productivity. An experiment was conducted by Tripathi (2003) to investigate the effects of N levels (80, 120, 160 and 200 kg ha^{-1}) on the growth, yield and quality of Indian mustard cv. Varuna. Nitrogen was applied at 3 equal splits, at sowing, at first irrigation and at 60 DAS. Results showed that all the yield characters except number of branches increased with increasing N levels up to 160 kg N ha^{-1}. The number of branches $plant^{-1}$ increased up to 200 kg N ha^{-1}. Net returns were maximum (Rs. 19 901 ha^{-1}) at 160 kg N ha^{-1} because seed yield was also maximum at this N rate. The benefit: cost ratio increased up to 160 kg N ha^{-1}.

Field experiments were conducted by Abdin *et al.* (2003) to study the effects of S and N on the yield and quality of Indian mustard cv. Pusa Jai Kisan (V_1) and rape cv. Pusa Gold (V_2). The treatments comprised: T_1 [(S0:N (50 + 50)]; T_2 [S40:N (50 + 50)] for V_1 and [S40:N(50 + 25 + 25) for V_2]; and T_3 [(S20 + 20):N(50 + 50) for V_1] and S(20 + 10 + 10):N(50 + 25 + 25) for V_2]. Split application of S and N (T_3) resulted in a significant increase in the seed yield of both crops. The average seed yield obtained from the different experimental sites in the three states was 3.89 t ha^{-1} for V_1 and 3.06 t ha^{-1} for V_2 under T_3. The average oil yield under T_3 was 1.71 t ha^{-1} for V_1 and 1.42 t ha^{-1} in V_2. The oil and protein contents in the seeds of V_1 and V_2 also increased with the split application of S and N. It may be concluded from these results that the yield and quality of rapeseed-mustard can be optimized with the split application of 40 kg S ha^{-1} and 100 kg N ha^{-1} during the appropriate phenological stages of crop growth and development.

Khan *et al.* (2003) observed that cycocel at 400 ppm + 60 kg N ha^{-1} and ethrel at 200 ppm + 80 kg N ha^{-1} enhanced leaf photosynthetic rate, water use efficiency, leaf area and leaf dry mass 80 days after sowing. The highest stem, pod and plant dry mass were noted 120 days after sowing. At maturity, pod number and seed yield increased. Singh *et al.* (2003) stated that N at 120 kg ha^{-1} produced 4.51 times higher number of branches, 48.03 times higher siliquae number, 2.09 g siliquae weight, 2.05 g higher seed weight $plant^{-1}$ and 2.55 q ha^{-1} higher seed yield compared to 60 kg N ha^{-1}. The N level higher than 120 kg ha^{-1} did not increase the yield and yield attributes significantly. The basis of N application did not significantly affect the performance of the plants.

Babu and Sarkar (2002) reported that mustard cultivars responded to N application up to 80 kg ha^{-1}. Dry matter yield, N content and N uptake by mustard cultivars significantly increased with an increase in the level of fertilizer N. Successive levels of N also increased significantly the uptake of soil N by mustard cultivars clearly establishing the 'priming' or 'added nitrogen interaction effect' of applied nitrogen. Meena *et al.* (2002) reported that the application of 60 kg N ha^{-1} registered significantly higher seed and stover yield of mustard over control and 30 kg N ha^{-1} and found statistically at par with 90 kg N ha^{-1}.

Singh (2002) found that application of N and P increased the length of siliquae, number of siliquae $plant^{-1}$, seeds $siliquae^{-1}$, seed yield and 1000-seed weight of mustard. However, the significant increase in yield and yield components was recorded in 60, 90 and 120 kg N ha^{-1} and 30, 45 and 60 kg P ha^{-1} treatments. The maximum seed yield was recorded from application of 45 kg P ha^{-1} (11.43 and 13.85 q ha^{-1} in 1999 and 2000, respectively) and 120 kg N ha^{-1} (12.98 and 13.83 q ha^{-1} in 1999 and 2000, respectively).

Sharawat *et al.* (2002) observed that the yield generally increased with the increase in N and S rate. N at 120 kg ha^{-1} resulted in the highest number of siliquae $plant^{-1}$ (397.25), weight of siliquae $plant^{-1}$ (33.32 g), number of seeds $siliquae^{-1}$ (14.80), seed yield $plant^{-1}$ (368.75 g), 1000-grain weight (17.33 g) and seed yield ha^{-1} (17.33 quintal). Budzynski and Jankowski (2001) investigated the effects of pre-sowing application of NPK (161 kg ha^{-1}) + S (30 kg ha^{-1}) or Mg (5 kg ha^{-1}) and top dressing of N (0, 30, 25+5 and 60 kg ha^{-1}) on the yield, yield components and morphological features of white mustard [Sinapis alba] and Indian mustard seeds in an experiment conducted in Poland. N top dressing (30, 25+5 and 60 kg ha^{-1}) increased the height, diameter of stem base and branching of Indian mustard and white mustard stems. Both crops, however, exhibited lodging. The effects of NPKS and NPKMg on the yield potential of white mustard were not dependent on weather conditions. N applied at 30 kg ha^{-1} at the start of the flowering period gave the best results among the methods of white mustard top dressing. Splitting this rate to 25 kg N ha^{-1} as a solid fertilizer and 5 kg N ha^{-1} in a solution gave results similar to that of the whole rate of 30 kg N ha^{-1} as a solid fertilizer. N at 60 kg ha^{-1} appeared to be less productive. N applied as a solid fertilizer at a rate of up to 60 kg ha^{-1} increased the seed yield.

2.2 Effect of sulphur on growth, yield and yield components of rapeseed

Ray *et al.* (2015) revealed that yield attributes and yield of crop were highest with 60 kg S ha^{-1}, mostly at par with 45 kg S ha^{-1}. Katiyar *et al.* (2014) reported that application of sulphur @ 25 kg ha^{-1} basal had significant influence on yield attributes and grain yield of mustard. This might due to increase in number of leaves, plant height with increase in levels of S. Similar finding was obtained by Hemantrajan and Triwedi (2004).

Neha *et al.* (2014) reported that application of 40 kg S ha^{-1} recorded significantly higher seed yield (19.6 q ha^{-1}) and stover yield (70.9 q ha^{-1}) over 20 kg S ha^{-1} and no S higher to this level remained at par with each other. Application of 40 kg S ha^{-1} gave significantly higher seed and stover yield by registering 12.9 and 13.5% higher over no S. Further, increase in S levels up to 60 kg S ha^{-1} remained at par with above level. Ray *et al.* (2014) reported that application of sulphur @ 60 kg S ha^{-1} had significant beneficial effect on various growth parameters of mustard. This treatment was at par with 45 kg S ha^{-1} for plant height at 75 DAS and at harvest and for LAI at 40 DAS. But there were no significant difference among 30, 45 and 60 kg S ha^{-1} in number of primary branches $plant^{-1}$. Application of 60 kg S ha^{-1} attained appreciable more crop growth than 20 to 40 kg S ha^{-1}. Dry matter production increased with the age of plant and increase was accelerated between 45 and 90 DAS. Yield of mustard was increased with the increasing dose of S from 0 to 60 kg ha^{-1}. Higher yield was obtained with 60 kg S ha^{-1} resulting in 17.9 % increase over control.

Rao *et al.* (2013) reported that different levels of S application significantly influenced the yield attributing characters and yield over control. Sah *et al.* (2013) reported that application of sulphur @ 45 kg ha^{-1} increased number of siliquae $plant^{-1}$, test weight, seed yield and straw yield. Fertilization of 45 kg S ha^{-1}

produced the highest seed yield of 19.2 q ha^{-1} in comparison to 13.2 q ha^{-1} in control.

Baudh and Prasad (2012) reported that productivity increased with increasing level of S. Application of S was highly influenced with the application of 60 kg S ha^{-1} than 20 to 40 kg S ha^{-1}. The productivity such as biomass production, number of capsules, seed output and reproductive capacity with grain biological yield also increased with increasing levels of S. Begum *et al.* (2012) conducted field experiments to evaluate the effect of different levels of S (0, 20, 40, 60, and 80 kg ha^{-1}) on rapeseed variety BARI Sarisha-15. Results showed that the most of the growth parameters and yield attributes were significantly influenced by different doses of S. The growth parameters, yield and yield contributing characters were increased with the increasing levels of S fertilizer up to 60 kg S ha^{-1} and with the doses beyond that were found to decrease. All growth parameters like plant height and all yield components, such as number of siliquae $plant^{-1}$, seeds $siliquae^{-1}$, 1000-seed weight and seed yield $plant^{-1}$ were found maximum from the treatment with 60 kg S ha^{-1}, which was at par with 80 kg S ha^{-1}. The highest seed yield (1990 and 1896 kg ha^{-1}) was found when S was used @ 60 kg ha^{-1}. The same treatment gave 24.71 % and 24.32 % higher seed yield than the control treatment, which were statistically identical with 80 kg ha^{-1} of S in both the years. Chattopaddhyay and Ghosh (2012) reported that the increase in grain yield was significant in S treated plots over control but higher S level *i.e.* 60 kg S ha^{-1} failed to register higher yield increase over that at 45 kg S ha^{-1}. Grain yield of mustard increased significantly with increased levels of S up to 45 kg S ha^{-1}, above which decreasing trend was observed.

Jat *et al.* (2012) reported that the entire yield attributes (siliquae $plant^{-1}$, seeds $siliquae^{-1}$ and test weight) and yield (seed and stover) increased significantly with increasing rates of sulphur upto 40 kg ha^{-1}. But the biological yield increased significantly upto 60 kg S ha^{-1}. The seed yield increased by 24.8 % over no sulphur application. Kumar and Trivedi (2012) reported that seed and straw yields increased significantly with increasing level of sulphur up to highest level of 60 kg S ha^{-1}. Application of 20, 40 and 60 kg S ha^{-1} increased the seed yield over the control by 13.9, 28.1 and 28.4 %.

Sulphur fertilization with 45 kg ha^{-1} was more efficient than 60 kg S ha^{-1} in increasing the seed yield which might be supplemented with increased number of siliquae $plant^{-1}$ (*Patel et al.,* 2009) and seeds $siliquae^{-1}$ (Kumar *et al.,* 2011). The increasing level of sulphur increased plant height, number of primary branches, yield straw and leaf area index, relative growth rate and net assimilation rate at all the stages of crop growth (Piri *et al.*, 2011b). Sulphur, with its involvement in the metabolic processes, enhances the meristematic activity and thus causes higher apical growth with expansion of photosynthetic surface (Piri *et al.,* 2012).

Pachauri *et al.* (2012) reported that seed yield of mustard recorded under 90 kg S ha^{-1} were higher by 30.6, 21.1 and 3.7% over 0, 30 and 60 kg S ha^{-1}, respectively. The seed yield of mustard significantly increased with 60 kg S ha^{-1}, however, the stover yield of mustard increased significantly up to 90 kg S ha^{-1}. The number of pods $plant^{-1}$ significantly increased up to 60 kg S ha^{-1}. However, the highest number of pods $plant^{-1}$ was recorded with 90 kg S ha^{-1}. The difference between 60 and 90 kg S ha^{-1} was non-significant. The highest number of seeds pod^{-1} was recorded at 90 kg S ha^{-1}, which was at par with 60 kg S ha^{-1} and this was significantly superior over control and 30 kg S ha^{-1}.

Mohiuddin *et al.* (2011) also demonstrated 29.3% increase in mustard yield with 24 kg S ha^{-1} over zero S. Mustard crop produces higher plant height (Kashved *et al.,* 2010) and primary branches $plant^{-1}$ (Piri *et al.,* 2011b) at different levels of S as compared to the crop grown without S. Farhad *et al.* (2010) reported that application of sulphur @ 20 kg ha^{-1} produced the highest seed yield, 1000-seed weight and straw yield of soybean. Application of sulphur was reported to increase yield attributes and yield of Indian mustard (Kumar *et al.,* 2011; Patel *et al.*, 2009).

Kapur *et al.* (2010) reported that number of branches plant^{-1}, number of siliquae plant^{-1}, number of seeds siliquae^{-1} and test weight were recorded significantly higher with 60 kg S ha^{-1} but it was at par with 45 kg S ha^{-1} and 30 kg S ha^{-1} levels in case of number of branches plant^{-1} as well as found at par with 45 kg S ha^{-1} for number of siliquae plant^{-1}, no. of seeds siliquae^{-1} and test weight. The significantly higher seed yield was recorded with sulphur @ 60 kg ha^{-1} and higher straw yield was recorded with S fertilization @ 45 kg ha^{-1} which was at par with 60 kg S ha^{-1} and 30 kg S ha^{-1}. The increase in seed yield under S levels at 60, 45, 30 and 15 kg ha^{-1} was 45.0, 44.9, 41.0 and 23.0% over control. Parmar *et al.* (2010) reported that the significantly highest number of branches plant^{-1} and test weight was recorded with 45 kg S ha^{-1}. However, the control and 15 kg S ha^{-1} were found at par with each other. Application of 45 kg S ha^{-1} recorded significantly the highest seed yield (20.5 q ha^{-1}) which was 61.9, 26.9 and 10.0% higher over control, 15 and 30 kg S ha^{-1}, respectively. The 45 kg S ha^{-1} recorded 30.8, 17.6 and 3.8% higher stover yield over control, 15 and 30 kg S ha^{-1}, respectively. However, the 30 and 45 kg S ha^{-1} levels were statistically at par with each other. Yadav *et al.* (2010) reported that the maximum yield was obtained by the S application @ 40 kg ha^{-1}.

Khatkar *et al.* (2009) reported that more number of siliquae plant^{-1}, seed siliquae^{-1} and the test weight was also recorded with higher levels of S fertilization which ultimately resulted in higher seed yield. Different levels of S produces more seed yield of mustard (Chand and Goutam, 2009) as compared to the crop grown without S. Khalid *et al.* (2009) revealed that 40 kg S ha^{-1} produced highest biomass (9058 kg ha^{-1}) and seed yield (1656 kg ha^{-1}). Sharma *et al.* (2009) also observed that mustard seed yield increased significantly by 33% to 141% over control with the application of S. Significant improvement in the number of siliquae plant^{-1}, test weight, seed yield and stover yield was recorded with S fertilization as compared to control. Singh *et al.* (2009) reported that the yield attributes of mustard responded positively to sulphur application. Increase in the yield attributes as well as maximum seed yield, biological yield and harvest index was noticed with 60 kg S ha^{-1}.

Ceh *et al.* (2008) reported that application of 40 and 60 kg S ha^{-1} gave significantly higher yield of mustard over 20 kg S ha^{-1} and no S application. Faujdar *et al.* (2008) reported that sulphur fertilization at 40 kg S ha^{-1} remained at par with 60 kg S ha^{-1} and significantly increased the seed and stover yield to the tune of 26.2 and 12.4% and 18.5 and 8.5%, respectively over control and 20 kg S ha^{-1}. Makeen *et al.* (2008) reported that plant height, number of siliquae plant^{-1}, number of seeds siliquae^{-1}, weight of 1000 seeds, seed yield and harvest index were significantly influenced by application of S. Application of sulphur @ 60 kg ha^{-1} recorded the highest values with respect to these parameters. The seed yield increased to 25.5 q ha^{-1} at 60 kg S ha^{-1} as compared to 11.1 q ha^{-1} at control. These results are in agreement with the findings of Raut *et al.* (2000). Harvest index increased significantly and harvest index at 60 kg S ha^{-1} was higher than other treatments.

Sarangthem *et al.* (2008) also confirmed that the seed yield of mustard significantly increased from 9.5 to 10.9 q ha^{-1} with the increase in level of S from 0 to 40 kg ha^{-1}. Zizale *et al.* (2008) reported that there was significant difference in seed and straw yield of mustard under different levels of S. The seed yield was significantly increased under all levels of sulphur over control. The S45 was at par with S30, produced significantly higher seed yield than S15 and control S0, the maximum straw yield was registered under S45. But these differences were non-significant. Above findings are in accordance with those reported by Prakash *et al.* (2002) who observed that the yield of mustard increased with the increase in the S application rate up to 45 kg ha^{-1}.

Kumar and Yadav (2007) reported that a significant response of crop was observed up to 30 kg S ha^{-1} in seed and stover yields. Application of 30 kg S ha^{-1} produced more number of primary branches at 90 days after sowing as compared to control. Number of siliquae $plant^{-1}$ significantly increased up to 30 kg S ha^{-1}. The highest number of siliquae of 334.2 $plant^{-1}$ was recorded with 45 kg S ha^{-1}. The highest number of seeds $siliquae^{-1}$ was recorded at 45 kg S ha^{-1}, which was on a par with that of 30 kg S ha^{-1} and was significantly superior to the control and 15 kg S ha^{-1}. The maximum test weight of 4.63 g/1000 seeds was recorded with 45 kg S ha^{-1} and minimum in control (3.84 g/1000 seeds). The seed and stover yields were significantly influenced by different sulphur levels. The highest seed yield and stover yield were recorded at 45 kg S ha^{-1}, which were on a par with those of 30 kg S ha^{-1} and these were significantly superior to the control. The increase in the seed yield due to application of 15, 30 and 45 kg S ha^{-1} over control was 20.5, 42.3 and 48.0%, respectively.

Malhi *et al.* (2007) conducted field experiments to determine yield response of different *Brassica* (*B.*) oilseed species/cultivars to S deficiency and S fertilization. All *B.* species/cultivars responded positively for seed yield and most other parameters to S fertilizer in all 3 yr, but the magnitude of response varied with species/cultivar and year. Seed yield was highest with Cutlass *juncea* mustard in a dry year (2003), but was highest with hybrid canola (InVigor 2663) in years with above-average precipitation (2004 and 2005). Seed yield was usually maximized at the rate of 30 kg S ha^{-1} for all *B.* species/cultivars. The effects of S deficiency and applied S were more pronounced on seed than straw. In conclusion, S fertilizer requirements for optimum seed yield were similar for all the *B.* species/cultivars used in this study on S-deficient soil, but higher yielding types of *B.* would produce greater seed yield by using S more efficiently.

Malviya *et al.* (2007) reported that application of 60 kg S ha^{-1} showed slight improvement in production of silliqua plant^{-1}, seeds siliquae^{-1}, 1000-seed weight and seed yield of mustard over those of 30 kg S ha^{-1} but the differences were not significant. Tomar and Singh (2007) reported that application of 30 kg S ha^{-1} significantly improved the yield attributes, seed and stover yields of mustard. Singh and Singh (2007) reported that the seed and stover yields of linseed increased significantly when sulphur was applied.

Mani *et al.* (2006) reported that sulphur individually increased the number of siliquae plant^{-1} of mustard by 5.0 %, respectively as the dose of sulphur increased from 0 to 30 kg S ha^{-1}. Piri and Sharma (2006) reported that seed and straw yield increased significantly with increasing level of sulphur up to highest level of 45 kg S ha^{-1}. Application of 15, 30 and 45 kg S ha^{-1} increased the seed yield over the control by 9, 16 and 23%, respectively. All the yield attributes, seeds siliquae^{-1}, 1000-seed weight of Indian mustard increased significantly with increasing doses of S up to 45 kg ha^{-1}, however, the differences between 0 and 15 kg S ha^{-1} for siliquae plant^{-1} and 1000-seed weight and between 15 and 30 kg S ha^{-1} for seeds siliquae^{-1} and 1000-seed weight were not significant.

Malik *et al.* (2004) carried out the studies to assess the influence of different levels of S fertilization (0, 25, 50, 75, 100, 125 and 150 kg ha^{-1}). The results revealed that the highest seed yield (3725 kg ha^{-1}) was obtained with 100 kg ha^{-1} S which was however, at par with treatment where 125 kg S ha^{-1} was applied. While minimum seed yield (2870 kg ha^{-1}) was recorded in case of control i.e. with no S. Jat *et al.* (2003) concluded that application of 90 kg S ha^{-1} lead to significantly increase in seed and biological yield. Choudhary *et al.* (2003) who observed that seed yield of mustard significantly increased with 60 kg S ha^{-1}.

Singh *et al.* (2000) found that application of sulphur up to 45 kg ha^{-1} significantly increased the seed yield and its attributes. The results are in accordance with those of reported by Prakash *et al.* (2002), wherein they found that S at 60 kg ha^{-1} gave the highest 1000-seed weight. While the difference between 40 and 60 kg S ha^{-1} was found at par. Similarly, application of 20, 40 and 60 kg S ha^{-1} increased the straw yield over control by 19.9, 35.7 and 37.0 %, respectively. There results corroborated the findings of Pandey *et al.* (2003).

2.3 Combined effect of nitrogen and sulphur on yield and yield components of rapeseed

Kumar *et al.* (2016) revealed that the highest seed yield (2606.21 kg ha^{-1}) was obtained in 60 kg ha^{-1} S and 120 kg ha^{-1} N followed by 40 kg S ha^{-1} and 120 kg N ha^{-1} treatment which gave 2588.91 kg ha^{-1} seed yield while minimum seed yield (1417.02 kg ha^{-1}) was recorded in case of control *i.e.* with no S and N. Singh and Kumar (2014) conducted an experiment to find out the effect of different levels of N and S on seed yield and other characters on 'Varuna' variety of Indian mustard. Different levels, 40, 80 and 120 kg ha^{-1} nitrogen and 15, 30, and 45 kg ha^{-1} sulphur significantly out yielded the 0 kg ha^{-1} nitrogen and sulphur in seed and biological yield. Almost similar results were obtained in case of siliquae plant^{-1}, siliquae length, number of seed siliquae^{-1} and harvest index. The application of 120 kg N ha^{-1} and 45 kg S ha^{-1} was the best combination for getting higher seed yield with its better quality.

Ngezimana and Agenbag (2013) conducted an experiment to determine how canola responds to N with no (low) and high S rates under ideal conditions in a controlled environment, with N (0, 40, 80, 120 and 160 kg ha^{-1}) and S (0 and 40 kg ha^{-1}) fertilization rates. Nitrogen application significantly increased leaf area, hence dry mass accumulation and ultimately flowering and pod formation, but high N and S application levels during early growth stages may have a negative effect on growth. Significant interaction between N and S were shown, however the positive effects of S were more pronounced in the reproductive phases. In this experiment, conducted under controlled temperature and watering conditions, but short winter daylight lengths, yield components of canola as measured by the number of flowers and pods at 91 DAP tended to reach a peak at application rates of 120 kg N ha^{-1} and 40 kg S ha^{-1}.

Mansoori (2012) studied the effect of N and S on yield and yield components of canola (*Brassica napus* L). The results indicated 120 kg N ha^{-1} and 40 kg S ha^{-1} subjected as an optimized combination of N and S for higher seed yield of canola. Ahmed *et al.* (2011) conducted field experiments to evaluate the effects of N and S levels on canola. Branches $plant^{-1}$, pods $plant^{-1}$ and biological yield significantly increased with increase in N level and no significant increase in seeds $siliquae^{-1}$ and seed yields occurred beyond 120 kg N ha^{-1}. However, 1000-seed weight consistently decreased with increasing level of N. Siliquae $plant^{-1}$ and biological yield continually increased with increase in S level. Alternatively, significant increased in branches $plant^{-1}$, seeds $siliquae^{-1}$, seed weight, seed yields was noted with increase in S level up to 40 kg ha^{-1}. Applications of S and N in split significantly decreased seed yield as compared to sole applications. It is concluded that S and N application as sole at the rate of 40 and 120 kg ha^{-1}, respectively performed better than the rest of their levels and method of application.

Mohiuddin *et al.* (2011) conducted an experiment to observe the effect of different levels of N and S on growth, yield and yield contributing characters of mustard (SAU Sharisha-1). The plant height, the number of branches $plant^{-1}$, the number of siliquae $plant^{-1}$, seed and shoot yield increased with increasing N level up to 80 kg N ha^{-1}. Further increasing in N level *i.e.* 120 kg N ha^{-1} had a negative effect on seed yield. On the other hand, with increasing S levels plant height, slilqua $plant^{-1}$, 1000 seed weight increased significantly up to 16 kg S ha^{-1}. However, the number of branches $plant^{-1}$ and seed yield and shoot yield increased up to the highest dose of S (24 kg S ha^{-1}). Considering the combined effect of N and S, combination of 80 kg N and 16 kg S ha^{-1} produced the maximum seed yield (1738 kg ha^{-1}). Dongarkar *et al.* (2005) conducted a field experiment to study the effect of four levels of N (0, 25, 50, 75 kg ha^{-1}) and three levels of S (0, 20, 40 kg ha^{-1}) on growth, yield attributes and yield of mustard (*Brassica juncea*). The application of N and S significantly influenced the growth and yield of mustard. Plant height, number of branches, number of siliquae, test weight, seed yield and stover yield ha^{-1} were significantly superior with the application of 75 kg N ha^{-1} over 25 kg N ha^{-1} and control but at par with 50 kg N ha^{-1} and 40 kg S ha^{-1} over 20 kg S ha^{-1} and control. The combined effect of nitrogen and sulfur levels at 75 kg N × 40 kg S ha^{-1} in respect to number of siliquae $plant^{-1}$, seed yield $plant^{-1}$ and seed yield ha^{-1} was found significantly superior.

Cheema *et al.* (2003) carried out an investigation to see the interactive effects of N and S on the growth, seed yield and oil quality of canola (*Brassica napus* L.). Different growth and yield parameters of canola such as plant height at maturity, number of siliquae m^{-2}, number of seeds $siliquae^{-1}$ and 1000-seed weight were significantly affected by N and S levels. Maximum seed yield (2704 kg ha^{-1}) was attained where the crop was fertilized @ 120 kg N ha^{-1}.

Chapter 3

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

This chapter presents a brief description about experimental period, site description, climatic condition, crop or planting materials, treatments, experimental design and layout, crop growing procedure, fertilizer application, intercultural operations, data collection and statistical analyses.

3.1 Location

The field experiment was conducted at the Agronomy research field, Sher-e-Bangla Agricultural University, Dhaka during the period from November 2015 to February 2016. Geographically the experimental field is located at 23°46' N latitude and 90° 22' E longitude at an elevation of 8.2 m above the sea level belonging to the Agro-ecological Zone "AEZ-28" of Madhupur Tract (BBS, 2011). The location of the experimental site has been shown in Appendix I.

3.2 Soil

The soil of the research field is slightly acidic in reaction with low organic matter content. Top soil was silty clay in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. Soil p^H was 5.47-5.63 and has organic carbon 0.89%. The experimental area was flat having available irrigation and drainage system and above flood levels. The selected plot was medium high land.

3.3 Climate

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 weather data during the study period at the experimental site are shown in Appendix II.

3.4 Plant material

BARI Sarisha-14 (*Brassica campestries*) developed by the Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur was used as planting material in this experiment. The seed was collected from the BARI. Before sowing germination test of seeds were done in the laboratory and percentage of germination was found over 95%.

3.5 Experimental treatments

The experiment consisted of two treatment factors as mentioned below:

a) Factor A: Nitrogen levels designated as:

i) N_0 = 0 kg N ha^{-1} (control)
ii) N_1 = 60 kg N ha^{-1}
iii) N_2 = 120 kg N ha^{-1}
iv) N_3 = 180 kg N ha^{-1}

b) Factor B: Sulphur levels designated as:

i) S_0 = 0 kg S ha^{-1} (control)
ii) S_1 = 15 kg S ha^{-1}
iii) S_2 = 30 kg S ha^{-1}
iv) S_3 = 45 kg S ha^{-1}

3.6 Design and layout

The experiment was laid out in a split plot design with three replications. The size of the individual plot was 4 m × 2.5 m = 10 m^2 and total numbers of plots were 48. There were 16 treatment combinations. Each block was divided into 16 unit plots. Nitrogen levels were placed at the main plots and sulphur levels were placed at the sub plots. Layout of the experiment was done on November

04, 2015 with interplot spacing of 0.50 m and inter block spacing of 0.75 m. Plant spacing was maintained with 30 cm and 5 cm, as of line to line and plant to plant distance, respectively. A layout of the experimental plot is given on Appendix VII.

3.7 Land preparation

The land of the experimental field was first opened on October 25, 2015 with a power tiller. Then it was exposed to the sun for 7 days prior to the next ploughing. Thereafter, the land was ploughed and cross-ploughed to obtain good tilth. 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. According to the layout of the experiment, the entire experimental area was divided into blocks and subdivided into plots for the sowing of rapeseed. In addition, irrigation and drainage channels were prepared around the plots.

3.8 Fertilizer application

The experimental plots were fertilized with a recommended dose 180, 100, 180, 5 and 10 kg ha^{-1} of N, P_2O_5, K_2O, ZnO, and Boric acid respectively (BARI 2011). Half of N in the form of urea and total amount of all other fertilizers of each plot were applied and incorporated into soil during final land preparation. Rest of the urea for corresponding N was top dressed according to treatments. After preparing layout, S fertilizers in the form of gypsum were applied as per treatments (0 kg S ha^{-1}, 15 kg S ha^{-1}, 30 kg S ha^{-1}, 45 kg S ha^{-1}).

3.9 Seed Sowing

Sowing was done on 6^{th} November, 2015 in rows 30 cm apart. Seeds were sown continuously in rows at a rate of 7 kg ha^{-1}. After sowing, the seeds were covered with the soil and slightly pressed by hand. Plant population was kept constant through maintaining plant to plant distant 5 cm in row.

3.10 Intercultural operations

The following intercultural operations were done for ensuring the normal growth of the crop.

3.10.1 Weeding and thinning

The optimum plant population was maintained by thinning excess plant at 15 days after sowing (DAS). One weeding with khurpi was given on 25 DAS. Thinning was done in the entire plots with care to maintain a constant plant population in the entire plot.

3.10.2 Irrigation

Irrigation was done at three times. The first irrigation was given in the field on 1st December 2015 at 25 DAS through irrigation channel. The second irrigation was given at the stage of maximum flowering (35 DAS) on 11th December 2015. The final irrigation was given at the stage of seed formation (50 DAS), on 27th December 2015.

3.10.3 Crop protection

The crop was sprayed with Malathion 57 EC@ 2ml L^{-1} of water at siliquae formation stage to control aphids. The crop was kept under constant observations from sowing to harvesting.

3.11 General observations of the experimental field

Regular observations were made to see the growth stages of the crop. In general, the field looked nice with normal green plants which were vigorous and luxuriant in the treatment plots than that of control plots.

3.12 Sampling

Ten sample plants were collected randomly from each plot. These 10 plants were used for taking data for yield attributes.

3.13 Harvest and post-harvest operation

When 80 % siliquae was matured and turned straw yellowish in color, the crop was harvested. To avoid shattering, harvesting was done in the morning. 1.0 m^2 (1.25 m × 0.8 m) were harvested from each plot and the harvested yield was recalculated to 1.0 m^2 area of plots. The harvested plant from the centre of each plot were bundled separately, tagged and brought to a clean cemented threshing floor. The same procedure was followed for sample plants.

3.13.1 Threshing

The crop bundles were sun dried for four days by spreading them on the threshing floor. Seeds were separated from the stover by beating the bundles with bamboo sticks and rubbing.

3.13.2 Drying

Seeds and stover were cleaned and dried in the sun for 4 consecutive days. After drying, seeds were kept in polythene bags.

3.13.3 Cleaning and weighing

Dried seeds and stovers were weighed plot wise. After that, the weights were converted into t ha^{-1}.

3.14 Collection of crop characters data

Ten plants in each plot were selected and tagged. All the growth data were recorded from those 10 selected plants. The following data were recorded during the experimentation.

A. Crop growth parameters

i. Plant height (cm) at 25, 35, 45, 55 DAS and at harvest
ii. Number of branches $plant^{-1}$ at 35, 45, 55 DAS and at harvest

B. Yield contributing characters

i. Number of siliquae plant^{-1}
ii. Siliqua length (cm)
iii. Number of seeds siliqua^{-1}
iv. Weight of 1000 seeds (g)

C. Yield and harvest index

i. Seed yield (t ha^{-1})
ii. Stover yield (t ha^{-1})
iii. Biological yield (t ha^{-1})
iv. Harvest index (%)

3.15 Methods of recording data

A. Crop growth parameters

i. Plant height (cm)

The height of the rapeseed plants was recorded at 25, 35, 45, 55 DAS and at harvest. The heights of 10 preselected sample plants were measured from the ground level to the tip of the shoot. Then the data was averaged and expressed in cm.

ii. Number of branches plant^{-1}

Total number of branches were taken at 35, 45, 55 DAS and at harvest. All the branches present on sampled plants were counted and averaged them to have number of branches plant^{-1}.

B. Yield contributing characters

i. Number of siliquae plant^{-1}

Number of siliquae was counted from 10 sample plants after harvest and mean number was expressed per plant basis.

ii. Siliquae length (cm)

The lengths of 10 randomly selected siliquae were measured from sample plants. Mean data was expressed in centimeter (cm).

iii. Number of seeds siliqua^{-1}

Number of total seeds of 10 sample plants from each plot was noted and the mean number was expressed per siliqua basis.

iv. Weight of 1000 seeds (g)

One thousand sun dried and cleaned seeds were counted randomly from the seed stock. Weight of 1000 seeds were then recorded by means of a digital electrical balance and expressed in g.

C. Yield and harvest index

i. Seed yield (t ha^{-1})

Seeds obtained from harvested area of each unit plot were dried in the sun and weighed. The seed weight was expressed as t ha^{-1}. Seed moisture content was measured by using digital moisture meter.

ii. Stover yield (t ha^{-1})

The stovers obtained from the harvested area of each unit plot were dried separately and weights were recorded. These weights were converted to t ha^{-1}.

iii. Biological yield (t ha^{-1})

Biological yield was calculated by using the following formula:

Biological yield= Seed yield + Stover yield

iv. Harvest index (%)

Harvest index is the relationship between seed yield and biological yield (Gardner *et al.,* 1985). It was calculated by using the following formula:

$$\text{HI (\%)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

3.16 Statistical analysis

The data obtained for different crop characters were statistically analyzed following the analysis of variance techniques by using MSTAT-C computer package programme. The significant differences among the treatment means were compared by Least Significant Difference (LSD) test at 5% level of probability (Gomez and Gomez, 1984).

Chapter 4

Results and Discussion

CHAPTAR IV

RESULTS AND DISCUSSION

This chapter comprises presentation and discussion of the results obtained from the study. The results of the yield and yield characters are influenced by different doses of nitrogen and sulphur treatments have been presented and discussed in this chapter.

4.1 Plant height (cm)

4.1.1 Effect of nitrogen levels

Different nitrogen levels showed significant effect on plant height of rapeseed at different DAS (Appendix III and Figure 1). The figure demonstrated that plant height showed an increasing trend with increasing the N levels upto 120 kg N ha^{-1} after that plant height showed decreasing trend with increasing N levels for different age of the plant upto harvest. The rate of increase was found rapid upto 45 DAS after that plant height increased sharply upto harvest irrespective of all nitrogen levels. It can be observed from the figure that 120 kg N ha^{-1} showed the tallest plant (16.83, 50.17, 81.96, 83.32 and 84.69 cm) and 0 kg N ha^{-1} produced the shortest plant (13.62, 42.15, 68.52, 68.94 and 69.37 cm) for sampling dates of 25, 35, 45, 55 DAS and at harvest, respectively. Increase N application levels significantly increased plant height as mentioned by Ahmadi and Bahrani (2009); Ahmadi (2010).

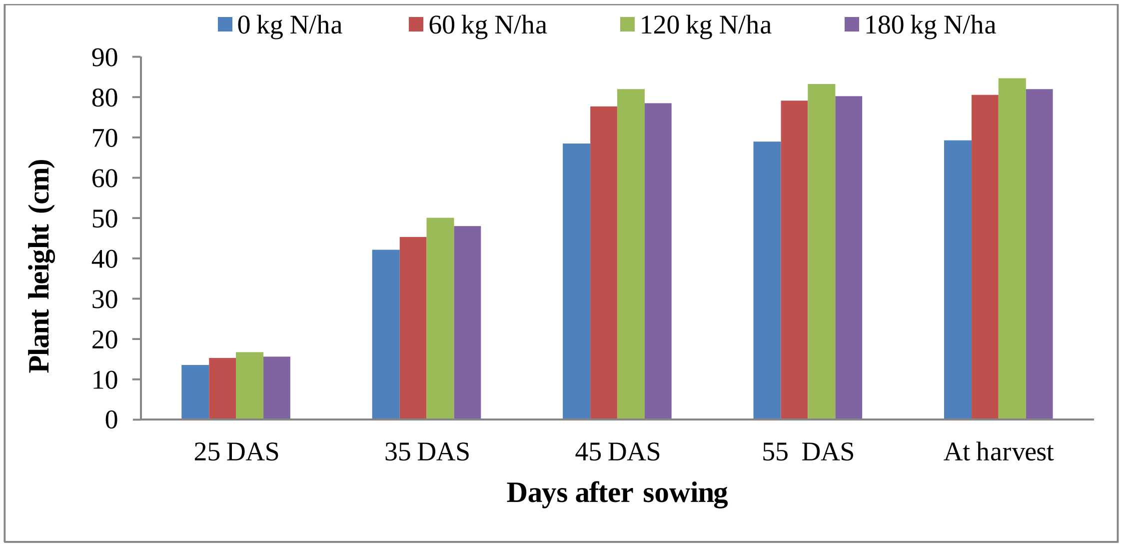

Figure 1. Effect of nitrogen on plant height of rapeseed at different days after sowing (DAS) ($LSD_{(0.05)}$= 0.68, 1.45, 2.83, 2.48 and 3.07 at 25, 35, 45, 55 DAS and at harvest, respectively)

4.1.2 Effect of sulphur levels

The significant result was found in plant height of rapeseed by the sulphur application at different growth stages (Appendix III and Figure 2).The figure demonstrated that plant height showed an increasing trend with increasing the age of plant upto harvest for all sulphur levels. The rate of increase was found rapid upto 45 DAS after that plant height increased sharply upto at harvest irrespective of all sulphur levels. It can be observed from the figure that 45 kg S ha^{-1} showed the tallest plant (15.78, 47.08, 78.72, 80.08 and 81.82 cm) and 0 kg S ha^{-1} produced the shortest plant (14.93, 45.26, 75.21, 75.79 and 76.16 cm) for sampling dates of 25, 35, 45, 55 DAS and at harvest, respectively. The increase in plant height with the application of sulphur is attributed to increased metabolic processes in plants with sulphur application which seems to have promoted meristematic activities resulting in higher apical growth and expansion of photosynthetic surface. Increase in plant height with an increase in rate of sulphur application has also been reported by a number of workers (Rana *et al.*, 2001; Govahi and Saffari, 2006; Piri *et al.*, 2011a).

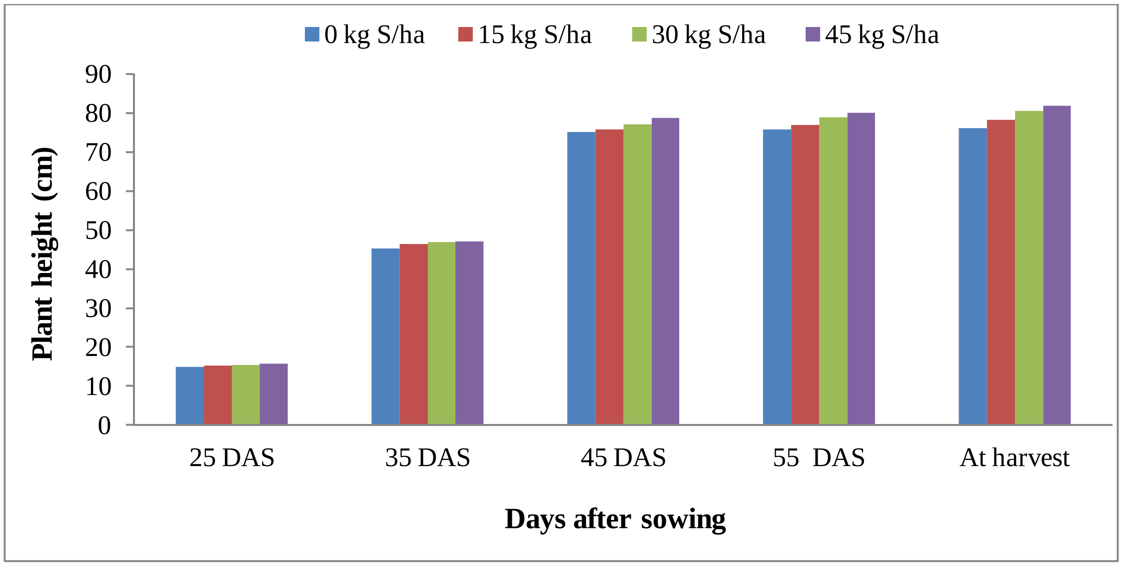

Figure 2. Effect of sulphur on plant height of rapeseed at different DAS ($LSD_{(0.05)}$ = 0.50, 0.87, 1.05, 1.12 and 1.43 at 25, 35, 45, 55 DAS and at harvest, respectively)

4.1.3 Combined effect of nitrogen and sulphur levels

Combination of N and S had significant effect on plant height of rapeseed at different DAS (Appendix III and Table 1). At 25 DAS, the tallest plant height (17.71 cm) was obtained from combination of 120 kg N and 45 kg S ha^{-1} which was statistically similar (17.15, 16.86 and 16.85 cm, respectively) with 120 kg N × 30, 15 kg S ha^{-1} and 180 kg N × 0 kg S ha^{-1}, respectively and the smallest height (12.87 cm) was obtained from the control treatment which was statistically similar (13.14 cm) with 0 kg N ha^{-1} × 15 kg S ha^{-1}, respectively. At 35, 45, 55 DAS and at harvest, the tallest plant heights (53.69, 84.98, 85.64 and 87.07 cm) were obtained from combination of 120 kg N and 45 kg S ha^{-1} and the smallest heights (39.27, 61.35, 62.89 and 58.99 cm, respectively) were obtained from control treatment. Similar result was also found by Mohiuddin *et al.* (2011).

Table 1. Combined effect of different levels of nitrogen and sulphur on plant height of rapeseed at different DAS

Nitrogen × Sulphur level	Plant height (cm) at				
	25 DAS	35 DAS	45 DAS	55 DAS	Harvest
N_0S_0	12.87 j	39.27 j	61.35 j	62.89 j	58.99 i
N_0S_1	13.14 ij	41.81 i	65.90 i	66.86 i	67.78 h
N_0S_2	14.01 hi	43.03 hi	71.26 h	72.93 h	73.85 g
N_0S_3	14.48 gh	44.50 gh	74.03 g	74.63 h	76.86 f
N_1S_0	14.40 gh	43.15 hi	75.79 fg	77.24 g	78.47 ef
N_1S_1	15.23 e-g	45.02 fg	77.03 ef	78.22 fg	79.54 d-f
N_1S_2	15.63 d-f	45.39 fg	78.32 de	79.87 d-f	81.20 c-e
N_1S_3	16.22 b-d	47.72 de	79.83 b-d	81.39 b-e	83.27 bc
N_2S_0	15.59 d-f	46.45 ef	80.37 b-d	81.89 b-d	83.33 bc
N_2S_1	16.86 a-c	48.74 cd	80.97 bc	82.42 bc	83.34 bc
N_2S_2	17.15 ab	51.78 b	81.50 b	83.34 b	85.02 ab
N_2S_3	17.71 a	53.69 a	84.98 a	85.64 a	87.07 a
N_3S_0	16.85 a-c	52.18 ab	81.79 b	82.69 b	83.84 bc
N_3S_1	15.99 c-e	50.02 c	79.05 c-e	80.41 c-f	82.33 b-d
N_3S_2	15.04 e-h	47.51 de	77.22 ef	79.44 e-g	82.06 cd
N_3S_3	14.73 f-h	42.41 i	76.04 fg	78.65 fg	80.07 de
$LSD_{(0.05)}$	1.09	1.73	2.10	2.24	2.87
CV (%)	3.82	2.21	1.62	1.70	2.15

Numbers followed by the same letter are not significantly different at $p \leq 0.05$ according to the LSD test

N_0 = 0 kg N ha^{-1} (control), N_1 = 60 kg N ha^{-1}, N_2 = 120 kg N ha^{-1}, N_3 =180 kg N ha^{-1}; S_0 = 0 kg S ha^{-1} (control), S_1 = 15 kg S ha^{-1}, S_2 = 30 kg S ha^{-1}, S_3 = 45 kg S ha^{-1}

4.2 Number of branches plant^{-1}

4.2.1 Effect of nitrogen levels

Different nitrogen levels had significant effect on number of branches plant^{-1} at different growth intervals of rapeseed under study (Appendix IV and Figure 3). The figure indicated that branch number increased with increasing the N levels upto 120 kg N ha^{-1} after that number of branches plant^{-1} showed decreasing trend with increasing N levels with advancement of growing time upto harvest. It can be concluded from the figure that 120 kg N ha^{-1} produced the maximum branch number plant^{-1} (6.01, 6.26, 6.45 and 6.52) and 0 kg N ha^{-1} showed the lowest (3.35, 3.59, 3.82 and 3.83) at 35, 45, 55 DAS and at harvest. Khan *et al.* (2002) and Uddin *et al.* (1992) reported that number of branches plant^{-1} increased with increasing levels of N up to 120 and 150 kg N ha^{-1}, respectively.

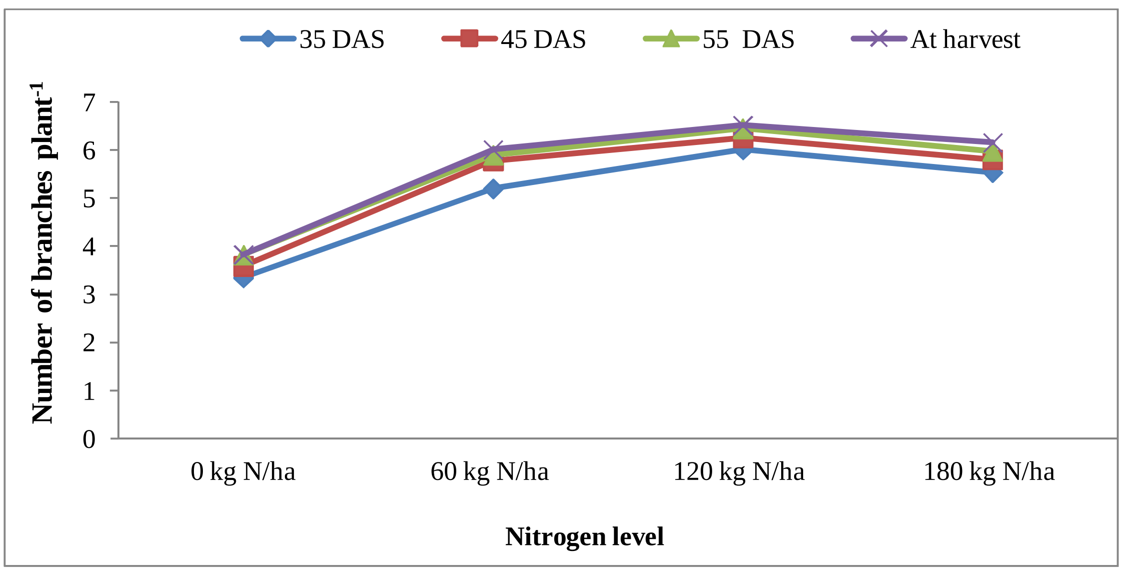

Figure 3. Effect of nitrogen on number of branches plant^{-1} of rapeseed at different DAS (LSD$_{(0.05)}$ = 0.49, 0.22, 0.20 and 0.45 at 35, 45, 55 DAS and at harvest, respectively)

4.2.2 Effect of sulphur levels

The significant result was found in number of branches plant^{-1} of rapeseed at different sulphur levels (Appendix IV and Figure 4). The figure demonstrated that number of branches plant^{-1} increased with increasing the age of plant irrespective of sulphur levels. It can be inferred from the figure that 45 kg S ha^{-1} showed the maximum branch number plant^{-1} (5.40, 5.59, 5.86 and 6.09) and control treatment produced the lowest (4.64, 5.12, 5.28 and 5.28) for sampling dates of 35, 45, 55 DAS and at harvest. The increase in number of primary branches of plant due to 45 kg S ha^{-1} may be due to enhanced photosynthesis, as sulphur is moved in the formation of chlorophyll and activation of enzymes. Similar results were also reported by Chauhan *et al.* (1996); Rana *et al.* (2001); Piri *et al.* (2011a).

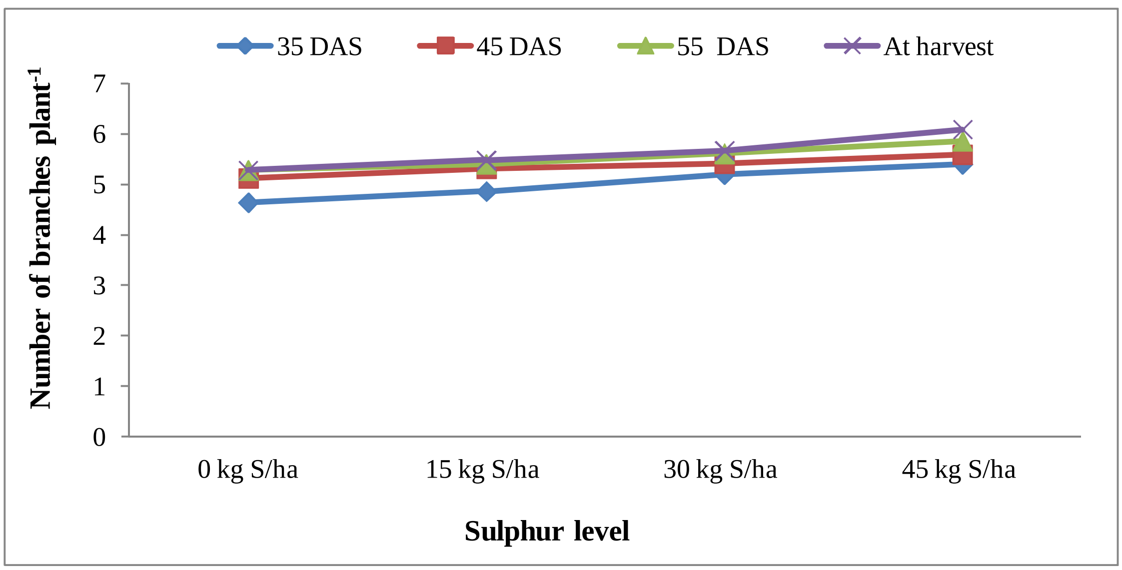

Figure 4. Effect of sulphur on number of branches plant^{-1} of rapeseed at different DAS ($LSD_{(0.05)}$ = 0.26, 0.31, 0.30 and 0.38 at 35, 45, 55 DAS and at harvest, respectively)

4.2.3 Combined effect of nitrogen and sulphur levels

Due to the combined effect of nitrogen and sulphur, the number of branches plant^{-1} of rapeseed was significantly affected at different growth stages (Appendix IV and Table 2). At 35, 45, 55 DAS and at harvest, the maximum numbers of branches plant^{-1} (6.60, 6.67, 6.79 and 7.27) were obtained from combination of 120 kg N and 45 kg S ha^{-1} which were statistically similar with 180 kg N × 0 S ha^{-1}, 120 kg N ha^{-1} × 30 kg S ha^{-1}, respectively. Contrary to that, the minimum numbers of branches (2.67, 2.87, 2.93 and 3.00) were obtained from control treatments which were statistically similar with 0 kg N × 15 kg S ha^{-1}. Fismes *et al.* (2000) reported that N increases vegetative growth and S improves N use efficiency and the present increase in branches plant^{-1} could be the consequence of improved N use efficiency.

Table 2. Combined effect of different levels of nitrogen and sulphur on number of branches plant^{-1} of rapeseed at different DAS

Nitrogen × Sulphur levels	Number of branches plant^{-1} at			
	35 DAS	45 DAS	55 DAS	Harvest
N_0S_0	2.67 j	2.87 i	2.93 g	3.00 i
N_0S_1	3.00 j	3.30 hi	3.33 g	3.40 hi
N_0S_2	3.60 i	3.63 h	4.13 f	3.93 h
N_0S_3	4.13 h	4.57 g	4.87 e	5.00 g
N_1S_0	4.27 h	5.47 ef	5.57 d	5.47 fg
N_1S_1	5.00 fg	5.60 de	5.73 cd	5.73 d-f
N_1S_2	5.57 de	5.80 b-e	5.97 b-d	6.27 b-d
N_1S_3	5.97 b-d	6.27 a-c	6.32 a-c	6.57 bc
N_2S_0	5.50 d-f	5.75 c-e	6.20 a-c	5.93 c-f
N_2S_1	5.63 c-e	6.21 a-d	6.36 ab	6.20 b-e
N_2S_2	6.30 ab	6.41 ab	6.47 ab	6.67 a-c
N_2S_3	6.60 a	6.67 a	6.79 a	7.27 a
N_3S_0	6.13 a-c	6.40 ab	6.40 ab	6.73 ab
N_3S_1	5.80 b-e	6.13 a-d	6.18 bc	6.57 bc
N_3S_2	5.33 e-g	5.80 b-e	5.87 b-d	5.80 d-f
N_3S_3	4.90 g	4.87 fg	5.47 de	5.53 e-g
$LSD_{(0.05)}$	0.53	0.62	0.60	0.69
CV (%)	6.19	6.83	6.46	7.91

Numbers followed by the same letter are not significantly different at $p \leq 0.05$ according to the LSD test

N_0 = 0 kg N ha^{-1} (control), N_1 = 60 kg N ha^{-1}, N_2 = 120 kg N ha^{-1}, N_3 =180 kg N ha^{-1}; S_0 = 0 kg S ha^{-1} (control), S_1 = 15 kg S ha^{-1}, S_2 = 30 kg S ha^{-1}, S_3 = 45 kg S ha^{-1}

4.3 Number of siliquae plant^{-1}

4.3.1 Effect of nitrogen levels

Different nitrogen levels had significant effect on number of siliquae plant^{-1} of rapeseed (Appendix V and Table 3). The maximum number of siliquae plant^{-1} (77.20) was found from the 120 kg N ha^{-1} and the lowest (33.73) was recorded from the control (0 kg N ha^{-1}) treatment. These findings are in consonance to result reported by El-Habbasha and El-Salam (2010).

4.3.2 Effect of sulphur levels

The number of siliquae plant^{-1} of rapeseed affected significantly by sulphur application (Appendix V and Table 3). The maximum number of siliquae plant^{-1} (63.73) was found from the S_3 (45 kg S ha^{-1}) and the lowest (56.16) was recorded from the control (0 kg N ha^{-1}) treatment which was statistically similar (57.15) with S_3 (15 kg S ha^{-1}). Amanullah *et al.* (2011); Govahi and Saffari (2006) reported that the S fertilization significantly increased the number of siliquae plant^{-1} over control. Subhani *et al.* (2003) found that the number of siliquae plant^{-1} increased with increasing levels of S up to 40 kg ha^{-1}.

4.3.3 Combined effect of nitrogen and sulphur levels

Combination of nitrogen and sulphur application had significant effect on number of siliquae plant^{-1} of rapeseed (Appendix V and Table 4). The maximum number of siliquae plant^{-1} (80.27) was found from the N_2S_3 (120 kg N × 45 kg S ha^{-1}) which was statistically identical (79.67 and 76.43) with N_2S_2 (120 kg N × 30 kg S ha^{-1} and 180 kg N × 0 kg S ha^{-1}), respectively. The minimum number of siliquae plant^{-1} (25.80) was recorded from control (without N and S) treatment which was statistically identical (30.33 and 32.00) with 0 kg N × 15 and 30 kg S ha^{-1}, respectively. The successive increase in the number of siliquae $plant^{-1}$ under varied doses of nitrogen and sulphur may be due to availability of more nutrients for proper growth of plants at different stages of rapeseed crop. These findings are in full agreement to the results reported earlier by El-Habbasha and El-Salam (2010) and Yasari and Patwardhan (2006).

4.4 Siliqua length (cm)

4.4.1 Effect of nitrogen levels

Different nitrogen levels had significant effect on siliqua length of rapeseed (Appendix V and Table 3). The highest siliqua length (4.76 cm) was recorded from the 120 kg N ha^{-1} which was statistically at par (4.67 cm) with 180 kg N ha^{-1} and the lowest (4.42 cm) was obtained from the control (0 kg N ha^{-1}) treatment which was statistically similar (4.54 cm) with 60 kg N ha^{-1}, respectively. This could be due to the availability of more nutrients for proper development of vegetative parts of plant including siliquae under higher dose of nitrogen. These results are in full agreement with those observed by El-Kholy *et al.* (2007).

4.4.2 Effect of sulphur levels

Different rates of sulphur application exerted significant effect on siliqua length of rapeseed (Appendix V and Table 3). The highest siliqua length (4.70 cm) was recorded from the 45 kg S ha^{-1} and the lowest (4.49 cm) was obtained from the control (0 kg S ha^{-1}) treatment. These findings are in full agreement to those reported by Amanullah *et al.* (2011) and Piri *et al.* (2011a) who reported that the S fertilization significantly increased the siliqua length over control.

4.4.3 Combined effect of nitrogen and sulphur levels

Combination of nitrogen and sulphur application had significant effect on siliqua length of rapeseed (Appendix V and Table 4). The highest siliqua length (4.92 cm) was recorded from the 120 kg N × 45 kg S ha^{-1} which was statistically similar (4.80 cm) with 180 kg N × 0 kg S ha^{-1} and the lowest (4.16 cm) was obtained from control (without N and S) treatment.

4.5 Number of seeds siliqua^{-1}

4.5.1 Effect of nitrogen levels

Different nitrogen levels had significant effect on number of seeds siliqua^{-1} of rapeseed (Appendix V and Table 3). The maximum number of seeds siliqua^{-1} (30.33) was recorded from the 120 kg N ha^{-1} which was statistically identical (28.65 and 28.54) with 180 and 60 kg N ha^{-1} and the lowest (22.26) was obtained from the control (0 kg N ha^{-1}) treatment. Similar results were reported by Fathy *et al.* (2009) who found that use of higher dose of nitrogen in mustard crop increased the number of seeds siliqaue^{-1}.

4.5.2 Effect of sulphur levels

Different rates of sulphur application exerted significant effect on number of seeds siliqua^{-1} of rapeseed (Appendix V and Table 3). The maximum number of seeds siliqua^{-1} (28.42) was recorded from the 45 kg S ha^{-1} which was statistically similar (27.41 and 27.09) with 30 and 15 kg S ha^{-1} and the lowest (26.86) was obtained from the control (0 kg S ha^{-1}) treatment which was statistically at par (27.09 and 27.41) with 15 and 30 kg S ha^{-1}, respectively. Amanullah *et al.* (2011) reported that the S fertilization significantly increased the number of seeds siliqua^{-1} over control. In another study, Subhani *et al.* (2003) found that the number of seeds siliqua^{-1} increased with increasing levels of S up to 40 kg ha^{-1}.

4.5.3 Combined effect of nitrogen and sulphur levels

Combination of nitrogen and sulphur application had significant effect on number of seeds siliqua^{-1} of rapeseed (Appendix V and Table 4). The maximum number of seeds siliqua^{-1} (33.73) was recorded from the 120 kg N × 45 kg S ha^{-1} which was statistically similar (33.03) with 180 kg N × 0 kg S ha^{-1} and the minimum (18.60) was obtained from the control (without N and S) treatment. These results are in agreement with the findings of Mohiuddin *et al.* (2011).

4.6 1000-seed weight (g)

4.6.1 Effect of nitrogen levels

Different nitrogen levels showed significant effect on 1000-seed weight of rapeseed (Appendix V and Table 3). The highest 1000-seed weight (3.41 g) was found from the 120 kg N ha^{-1} which was statistically similar (3.25 and 3.23 g) with 180 and 60 kg N ha^{-1} and the lowest (3.12 g) was recorded from the control treatment which was statistically similar (3.23 and 3.25 g) with 60 and 120 kg N ha^{-1}, respectively. Ozer (2003), Singh (2002) and Shamsuddin *et al.* (1987) also obtained highest 1000-seed weight with 120 kg N ha^{-1}.

4.6.2 Effect of sulphur levels

Different rates of sulphur application exerted significant effect on 1000-seed weight of rapeseed (Appendix V and Table 3). The highest 1000-seed weight (3.35 g) was found from the 45 kg S ha^{-1} which was statistically identical (3.30 g) with 30 kg N ha^{-1} and the lowest (3.14 g) was obtained from the control (no S) treatment. Amanullah *et al.* (2011); Govahi and Saffari (2006) reported that the S fertilization significantly increased the 1000-seed weight over control. Subhani *et al.* (2003) obtained heavier seeds from 30 to 50 kg S ha^{-1}.

Table 3. Effect of different levels of nitrogen and sulphur on number of siliquae plant^{-1}, siliqua length, number of seeds siliqua^{-1}, 1000-seed weight of rapeseed

Nitrogen levels	Number of siliquae plant^{-1}	Siliqua length (cm)	Number of seeds siliqua^{-1}	1000-seed weight (g)
N_0	33.73 d	4.42 c	22.26 b	3.12 b
N_1	54.91 c	4.54 bc	28.54 a	3.23 ab
N_2	77.20 a	4.76 a	30.33 a	3.41 a
N_3	71.19 b	4.67 ab	28.65 a	3.25 ab
$LSD_{(0.05)}$	4.35	0.18	2.49	0.22
CV (%)	7.34	4.71	9.09	8.15
Sulphur levels				
S_0	56.16 c	4.49 c	26.86 b	3.14 c
S_1	57.15 bc	4.58 b	27.09 ab	3.23 b
S_2	59.99 b	4.61 b	27.41 ab	3.30 a
S_3	63.73 a	4.70 a	28.42 a	3.35 a
$LSD_{(0.05)}$	3.24	0.06	1.46	0.07
CV (%)	6.49	1.59	6.30	2.46

Numbers followed by the same letter are not significantly different at $p \leq 0.05$ according to the LSD test

N_0 = 0 kg N ha^{-1} (control), N_1 = 60 kg N ha^{-1}, N_2 = 120 kg N ha^{-1}, N_3 =180 kg N ha^{-1}; S_0 = 0 kg S ha^{-1} (control), S_1 = 15 kg S ha^{-1}, S_2 = 30 kg S ha^{-1}, S_3 = 45 kg S ha^{-1}

4.6.3 Combined effect of nitrogen and sulphur levels

Combination of nitrogen and sulphur application had significant effect on 1000-seed weight of rapeseed (Appendix V and Table 4). The highest 1000-seed weight (3.65 g) was found from 120 kg N ha^{-1} × 45 kg S ha^{-1} treatment which was statistically identical (3.58 g) with 120 kg N ha^{-1} × 30 kg S ha^{-1} and the lowest (2.93 g) was recorded from control (without N and S) treatment. The results were consistent with the findings of Mohiuddin *et al.* (2011).

Table 4. Combined effect of different levels of nitrogen and sulphur on number of siliquae plant^{-1}, siliqua length, number of seeds siliqua^{-1}, 1000-seed weight of rapeseed

Nitrogen × Sulphur levels	Number of siliquae plant^{-1}	Siliqua length (cm)	Number of seeds siliqua^{-1}	1000-seed weight (g)
N_0S_0	25.80 f	4.16 h	18.60 g	2.93 h
N_0S_1	30.33 f	4.36 g	22.20 f	3.12 fg
N_0S_2	32.00 f	4.41 fg	23.73 ef	3.20 d-g
N_0S_3	46.80 e	4.75 bc	24.50 ef	3.25 c-f
N_1S_0	48.13 e	4.40 fg	28.57 cd	3.13 e-g
N_1S_1	48.67 e	4.50 ef	28.23 cd	3.22 c-g
N_1S_2	59.50 d	4.58 de	28.27 cd	3.24 c-f
N_1S_3	63.33 cd	4.68 cd	29.10 cd	3.34 bc
N_2S_0	74.27 ab	4.58 de	27.33 de	3.10 g
N_2S_1	74.60 ab	4.74 bc	29.63 b-d	3.32 b-d
N_2S_2	79.67 a	4.78 bc	30.70 bc	3.58 a
N_2S_3	80.27 a	4.92 a	33.73 a	3.65 a
N_3S_0	76.43 a	4.80 ab	33.03 ab	3.41 b
N_3S_1	75.00 ab	4.71 bc	28.30 cd	3.26 c-e
N_3S_2	68.80 bc	4.68 cd	26.93 de	3.18 e-g
N_3S_3	64.53 cd	4.48 e-g	26.33 de	3.15 e-g
$LSD_{(0.05)}$	7.07	0.12	3.53	0.13
CV (%)	6.49	1.59	6.30	2.46

Numbers followed by the same letter are not significantly different at $p \leq 0.05$ according to the LSD test

N_0 = 0 kg N ha^{-1} (control), N_1 = 60 kg N ha^{-1}, N_2 = 120 kg N ha^{-1}, N_3 =180 kg N ha^{-1}; S_0 = 0 kg S ha^{-1} (control), S_1 = 15 kg S ha^{-1}, S_2 = 30 kg S ha^{-1}, S_3 = 45 kg S ha^{-1}

4.7 Seed yield (t ha^{-1})

Seed is the ultimate output of a crop which determines the efficiency of profitability of crop production enterprise.

4.7.1 Effect of nitrogen levels

Different doses of nitrogen fertilizer showed significant variation on the seed yield of rapeseed (Appendix VI and Table 5). The highest seed yield (1.67 t ha^{-1}) was found from the 120 kg N ha^{-1} which was statistically identical (1.59 t ha^{-1}) with 180 kg N ha^{-1} and the lowest (0.79 t ha^{-1}) was recorded from the control (0 kg N ha^{-1}) treatment. The increase in seed yield under all the three doses of the nitrogen was significantly higher as compared to 0 kg of N ha^{-1}. The results are in conformity with the finding of Seyedeh *et al*. (2012). Moreover, Cheema *et al.* (2001) reported that the seed yield of *Brassica* increased with increased N application from 0 to 90 kg ha^{-1}, while at the highest N application (120 kg ha^{-1}), *Brassica* seed yield was significantly reduced.

4.7.2 Effect of sulphur levels

Non-significant variation was observed on the seed yield of rapeseed when the field was fertilized with different doses of S (Appendix VI and Table 5). Numerically the highest seed yield (1.42 t ha^{-1}) was obtained from the 45 kg S ha^{-1} and the lowest (1.33 t ha^{-1}) was found from the control (0 kg N ha^{-1}) treatment. These findings are in consonance to result reported by Singh and Kumar (2014). Amanullah *et al.* (2011); Govahi and Saffari (2006) found that the S fertilization significantly increased the seed yield over control.

4.7.3 Combined effect of nitrogen and sulphur levels

Combined application of different doses of nitrogen and sulphur had significant effect on seed yield of rapeseed (Appendix VI and Table 6). The highest seed yield (1.83 t ha^{-1}) was obtained from the 120 kg N × 45 kg S ha^{-1} which was statistically similar (1.81 and 1.74 t ha^{-1}) with 180 kg N × 0 kg S ha^{-1} and 120 kg N × 30 kg S ha^{-1}, respectively. The lowest seed yield (0.69 t ha^{-1}) was found from control (0 kg N and S ha^{-1}) treatment which was statistically at par (0.71 and 0.77 t ha^{-1}) with 0 kg N × 15, 30 kg S ha^{-1}, respectively. Present study revealed that, increase in seed yield with the increase in N and S levels could be the consequences of the increase in yield components such as plant height, number of siliquae $plant^{-1}$ and seeds $siliqua^{-1}$. The positive impact of N on the seed yield of *Brassica* has been frequently reported by Hao *et al.* (2004). Brennan and Bolland (2008) reported that seed yield responses to applied S only occurred when N was applied and tended to increase as more N was applied. Likewise, Bishnoi *et al*. (2007) reported that the highest seed yield was obtained with 30 kg S ha^{-1} along with 228 kg N ha^{-1}. Results pertaining to the impact of S levels on seed yield of *Brassica*, are in agreement with Subhani *et al.* (2003) who achieved maximum seed yield from 40 to 50 kg S ha^{-1}. Likewise, Ahmad *et al.* (1999) stated that S fertilization increased seed yield of *Brassica* species by 30 to 46% as compared with control treatment. The increase in the seed yield could be a reflection of the effect of S on growth and development; it might be due to marked increase in the number of branches $plant^{-1}$ which gave a chance to the plant to carry more flowers, pods and hence more seeds. Similarly, Malhi *et al.* (2007) indicated that seed yield increased sharply with first 10 kg S ha^{-1} increment, and moderately with second increment.

4.8 Stover yield (t ha^{-1})

4.8.1 Effect of nitrogen levels

Different doses of N fertilizer showed significant variation on the stover yield of rapeseed (Appendix VI and Table 5). The highest stover yield (2.72 t ha^{-1}) was recorded from the 120 kg N ha^{-1} and the lowest (1.39 t ha^{-1}) was obtained from the control (0 kg N ha^{-1}) treatment. The present result corroborates with the findings of Mohiuddin *et al.* (2011).

4.8.2 Effect of sulphur levels

Variation in stover yield of rapeseed at different doses of sulphur was non-significant (Appendix VI and Table 5). Numerically the highest stover yield (2.24 t ha^{-1}) was recorded from the 45 kg S ha^{-1} and the lowest (2.06 t ha^{-1}) was obtained from the control (0 kg N ha^{-1}) treatment. This may be due to the effect of sulphur in increasing growth attributes and production of more dry matter with sulphur application. Jat *et al.* (2003); Piri *et al.* (2011a) also reported an increase in stover yield of mustard with increasing sulphur levels.

4.8.3 Combined effect of nitrogen and sulphur levels

Combined application of different doses of nitrogen and sulphur had significant effect on stover yield of rapeseed (Appendix VI and Table 6). The highest stover yield (2.85 t ha^{-1}) was recorded from 120 kg N ha^{-1} × 45 kg S ha^{-1} which was statistically similar (2.83, 2.74 and 2.46 t ha^{-1}, respectively) with 120 kg N × 30, 15 and 0 kg S ha^{-1}, respectively. The lowest stover yield (1.30 t ha^{-1}) was obtained from the control (without N and S) treatment which was statistically identical (1.31, 1.36 and 1.58 t ha^{-1}, respectively) with 0 kg N × 15, 30 and 45 kg S ha^{-1}, respectively. Interaction between N and S has been found positive and significant for stover yield (Singh and Kushwaha, 2012). Similar results were found by Mohiuddin *et al.* (2011).

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

4.9.1 Effect of nitrogen levels

The significant result was found in biological yield of rapeseed by the different levels of nitrogen (Appendix VI and Table 5). The highest biological yield (4.39 t ha^{-1}) was recorded from the 120 kg N ha^{-1} and the lowest (2.17 t ha^{-1}) was obtained from the control (0 kg N ha^{-1}) treatment. These findings are in consonance to result reported by Singh and Kumar (2014).

4.9.2 Effect of sulphur levels

Variation in biological yield of rapeseed at different doses of sulphur was significant (Appendix VI and Table 5). The highest biological yield (3.66 t ha^{-1}) was calculated from the 45 kg S ha^{-1} which was statistically similar (3.56 and 3.47 t ha^{-1}) with 30 and 15 kg S ha^{-1}, respectively and the lowest (3.39 t ha^{-1}) was recorded from the control (0 kg N ha^{-1}) treatment which was statistically similar (3.47 and 3.56 t ha^{-1}) with 15 and 30 kg S ha^{-1}, respectively. The results are in conformity with the findings of Singh and Kumar (2014).

4.9.3 Combined effect of nitrogen and sulphur levels

Biological yield of rapeseed was significantly affected due to the combined effect of different doses of nitrogen and sulphur (Appendix VI and Table 6). The highest biological yield (4.68 t ha^{-1}) was calculated from 120 kg N × 45 kg S ha^{-1} treatment combination which was statistically similar (4.57 and 4.36 t ha^{-1}, respectively) with 120 kg N × 30 and 15 kg S ha^{-1}, respectively and the lowest

(1.99 t ha^{-1}) was recorded from the control (0 kg N and S ha^{-1}) treatment which was statistically at par (2.02 and 2.13 t ha^{-1}) with 0 kg N × 15 and 30 kg S ha^{-1}, respectively. These findings are in consonance to result reported by Singh and Kumar (2014).

4.10 Harvest index (%)

Harvest index is an important trait in determining economic yield and represents an increased physiological capacity to mobilize photosynthates and translocate them to organs of economic value (Jamal *et al.,* 2006; Malhi *et al.,* 2007).

4.10.1 Effect of nitrogen levels

The significant result was found in harvest index of rapeseed by the different levels of nitrogen (Appendix VI and Table 5). The highest harvest index (40.54 %) was recorded from the 180 kg N ha^{-1} which was statistically similar (39.23 %) with 60 kg N ha^{-1} and the lowest (36.22 %) was obtained from the control (0 kg N ha^{-1}) treatment.

4.10.2 Effect of sulphur levels

Non-significant variation was observed in harvest index of rapeseed at different doses of sulphur (Appendix VI and Table 5). Numerically the highest harvest index (38.75 %) was found from the 45 kg S ha^{-1} and the lowest (38.15 %) was calculated from 15 kg S ha^{-1}. Amanullah *et al.* (2011) reported that the S fertilization significantly increased the harvest index over control.

Table 5. Effect of different levels of nitrogen and sulphur on seed, stover, biological yield and harvest index of rapeseed

Nitrogen levels	Seed yield ($t\ ha^{-1}$)	Stover yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest index (%)
N_0	0.79 c	1.39 c	2.17 d	36.22 c
N_1	1.41 b	2.17 b	3.58 c	39.23 ab
N_2	1.67 a	2.72 a	4.39 a	38.04 b
N_3	1.59 a	2.34 b	3.93 b	40.54 a
$LSD_{(0.05)}$	0.14	0.16	0.29	1.52
CV (%)	12.11	9.00	9.80	4.69
Sulphur levels				
S_0	1.33	2.06	3.39 b	38.62
S_1	1.34	2.13	3.47 ab	38.15
S_2	1.38	2.18	3.56 ab	38.51
S_3	1.42	2.24	3.66 a	38.75
$LSD_{(0.05)}$	ns	ns	0.23	ns
CV (%)	10.43	10.64	7.77	8.91

Numbers followed by the same letter are not significantly different at $p \leq 0.05$ according to the LSD test. ns: non-significant

N_0 = 0 kg N ha^{-1} (control), N_1 = 60 kg N ha^{-1}, N_2 = 120 kg N ha^{-1}, N_3 =180 kg N ha^{-1}; S_0 = 0 kg S ha^{-1} (control), S_1 = 15 kg S ha^{-1}, S_2 = 30 kg S ha^{-1}, S_3 = 45 kg S ha^{-1}

4.10.3 Combined effect of nitrogen and sulphur levels

Combined application of different doses of nitrogen and sulphur had significant effect on harvest index of rapeseed (Appendix VI and Table 6). The highest harvest index (43.52 %) was found from 180 kg N × 0 kg S ha^{-1} which was statistically similar (40.57, 40.53, 39.12, 38.13, 39.99, 39.89, 39.47, 38.55 and 38.47 %, respectively) with 180 kg N × 30, 15 kg S ha^{-1}, 120 kg N × 45, 30 kg S ha^{-1}, 60 kg N × 30, 45, 15, 0 kg S ha^{-1} and 0 kg N × 45 kg S ha^{-1}, respectively and the lowest (34.79 %) was calculated from control (without N and S) treatment which was statistically similar (35.29, 36.33, 38.47, 38.55, 39.47, 38.89, 38.99, 37.62, 37.31, 38.13, 39.12, 40.53 and 37.54 %) with 0 kg N × 15, 30, 45 kg S ha^{-1}, 60 kg N × 0, 15, 30, 45 kg S ha^{-1}, 120 kg N × 0, 15, 30, 45 kg S ha^{-1} and 180 kg N × 15, 45 kg S ha^{-1}, respectively.

Table 6. Combined effect of different levels of nitrogen and sulphur on seed, stover, biological yield and harvest index of rapeseed

Nitrogen × Sulphur levels	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
N_0S_0	0.69 g	1.30 d	1.99 h	34.79 c
N_0S_1	0.71 g	1.31 d	2.02 h	35.29 bc
N_0S_2	0.77 fg	1.36 d	2.13 gh	36.33 bc
N_0S_3	0.98 f	1.58 d	2.56 g	38.47 a-c
N_1S_0	1.33 e	2.11 c	3.44 f	38.55 a-c
N_1S_1	1.40 c-e	2.12 c	3.52 ef	39.47 a-c
N_1S_2	1.41 c-e	2.22 c	3.63 ef	38.99 a-c
N_1S_3	1.48 c-e	2.25 c	3.73 d-f	39.89 a-c
N_2S_0	1.49 c-e	2.46 a-c	3.95 c-e	37.62 bc
N_2S_1	1.63 a-c	2.74 ab	4.36 a-c	37.31 bc
N_2S_2	1.74 ab	2.83 a	4.57 ab	38.13 a-c
N_2S_3	1.83 a	2.85 a	4.68 a	39.12 a-c
N_3S_0	1.81 ab	2.37 bc	4.18 b-d	43.52 a
N_3S_1	1.61 a-d	2.36 bc	3.97 c-e	40.53 a-c
N_3S_2	1.58 b-d	2.33 c	3.91 c-e	40.57 ab
N_3S_3	1.38 de	2.29 c	3.67 ef	37.54 bc
$LSD_{(0.05)}$	0.24	0.38	0.46	3.09
CV (%)	10.43	10.64	7.77	8.91

Numbers followed by the same letter are not significantly different at $p \leq 0.05$ according to the LSD test

N_0 = 0 kg N ha^{-1} (control), N_1 = 60 kg N ha^{-1}, N_2 = 120 kg N ha^{-1}, N_3 =180 kg N ha^{-1}; S_0 = 0 kg S ha^{-1} (control), S_1 = 15 kg S ha^{-1}, S_2 = 30 kg S ha^{-1}, S_3 = 45 kg S ha^{-1}

Chapter 5

Summary and conclusion

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the Agronomy field of Sher-e-Bangla Agricultural University (SAU), Dhaka during the period from November, 2015 to February, 2016 to investigate the effect of nitrogen and sulphur on yield and yield components of rapeseed. The two-factor experiment included 4 doses of nitrogen *viz.,* 0 kg ha^{-1} (control), 60 kg ha^{-1}, 120 kg ha^{-1}, 180 kg ha^{-1}; and 4 doses of sulphur *viz.,* 0 kg ha^{-1} (control), 15 kg ha^{-1}, 30 kg ha^{-1}, 45 kg ha^{-1} was set up in split plot design with three replications. The size of the individual plot was 4 m × 2.5 m and total numbers of plots were 48. There were 16 treatment combinations. Nitrogen levels were placed at the main plots and sulphur levels were placed at the sub plots.

The data on plant height and number of branches $plant^{-1}$ were recorded at different days after seeding. Yield and yield contributing parameters like, number of siliquae $plant^{-1}$, siliqua length, number of seeds $siliqua^{-1}$, 1000-seed weight, seed yield, stover yield, biological yield and harvest index were recorded after harvest. Data were analyzed using MSTAT-C computerized package program. The mean differences among the treatments were compared by Least Significant Difference (LSD) test at 5% level of significance.

Results showed that different doses of nitrogen in rapeseed had significant effect on most of the yield and yield contributing parameters. Nitrogen applied with 120 kg ha^{-1} performed best results on plant height, number of branches $plant^{-1}$, number of siliquae $plant^{-1}$, siliqua length, number of seeds $siliqua^{-1}$, 1000-seed weight, seed yield, stover yield, biological yield and harvest index. Without nitrogen (0 kg N ha^{-1}) yield and yield contributing characters were affected severely.

Different doses of sulphur also influenced significantly the yield and yield contributing attributes except seed yield, stover yield and harvest index. Application of 45 kg S ha^{-1} performed best results on plant height, number of branches $plant^{-1}$, number of siliquae $plant^{-1}$, siliqua length, number of seeds $siliqua^{-1}$, 1000-seed weight and biological yield. Among the sulphur doses, the poorest result was found from the control (no sulphur) treatment.

Combined effect of different doses of nitrogen and sulphur also influenced significantly on the yield and yield contributing characters. Combination of 120 kg N and 45 kg S ha^{-1} produced the highest results of plant height, number of branches $plant^{-1}$, number of siliquae $plant^{-1}$, siliqua length, number of seeds $siliqua^{-1}$, 1000-seed weight, seed yield, stover yield, biological yield, and harvest index. The lowest yield due to poor yield contributing characters were attributed to the plots under control treatments.

Considering the results of the present experiment, it may be concluded that 120 kg N and 45 kg S ha^{-1} treatment combination was the best treatment as compared to those of other treatments. So, 120 kg N and 45 kg S ha^{-1} may be recommended for cultivation of rapeseed cv. BARI Sarisha-14 at Sher-e-Bangla Agricultural University farm and similar environment elsewhere in Bangladesh. However, it is worthy to verify the results across the country following diverse soil and climatic conditions as multi-locational trial of the crop.

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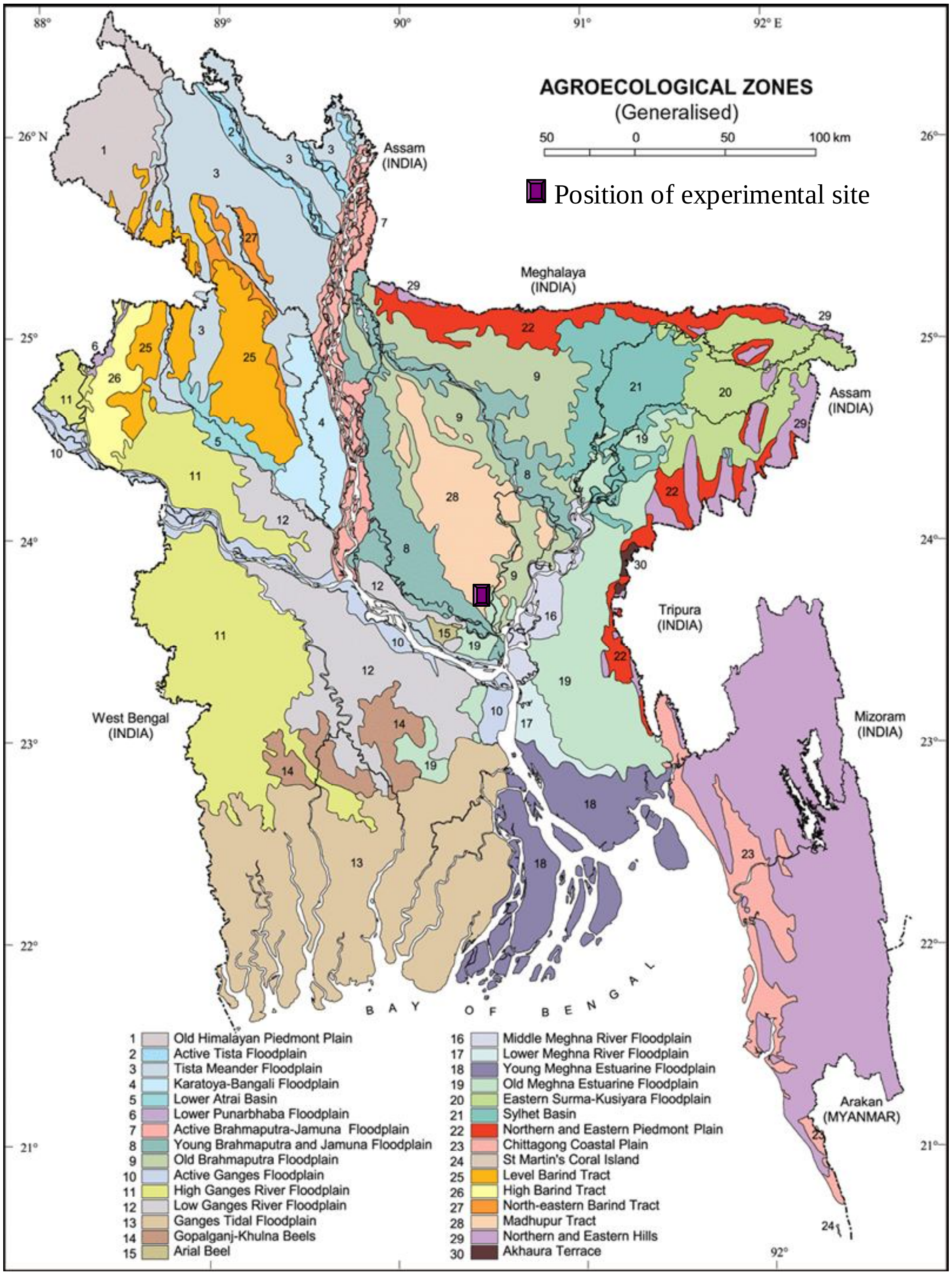
Appendices

APPENDICES

Appendix I. Map showing the experimental site under study



Appendix II. Weather data, 2015-2016, Dhaka

Year	Month	Average Air Temperature (^{o}C)		Average Relative Humidity (%)	Total Average Rainfall (mm)
		Minimum	Maximum		
2015	November	20.10	29.70	58.29	5
	December	15.84	26.93	68.58	0
2016	January	12.50	24.55	73.39	14
	February	24.61	36.86	75.16	34

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1207.

Appendix III. Mean square values for plant height of rapeseed at different DAS

Sources of variation	Degrees of freedom	Mean Square				
		Plant height (cm)				
		25 DAS	35 DAS	45 DAS	55 DAS	At harvest
Replication	2	1.5928	4.861	15.364	9.770	6.662
Nitrogen	3	21.0276**	144.151**	395.815**	467.982**	548.202**
Error (a)	6	0.4613	2.956	11.272	8.650	13.303
Sulphur	3	1.5164**	8.107**	29.480**	44.067**	75.033**
Nitrogen × Sulphur	9	2.3661**	33.681**	29.213**	31.225**	47.021**
Error (b)	24	0.3449	1.054	1.546	1.761	2.897

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

Appendix IV. Mean square values for number of branches palnt^{-1} of rapeseed at different DAS

Sources of variation	Degrees of freedom	Mean Square			
		Number of branches plant^{-1}			
		35 DAS	45 DAS	55 DAS	At harvest
Replication	2	0.9968	0.2113	0.05	0.2240
Nitrogen	3	16.2675**	17.2272**	16.5001**	17.7458**
Error (a)	6	0.3397	0.0694	0.0551	0.0615
Sulphur	3	1.3861**	0.4638**	0.7877**	1.4347**
Nitrogen × Sulphur	9	1.0746**	1.0867**	0.8098**	1.2027**
Error (b)	24	0.0966	0.1340	0.1281	0.1982

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

Appendix V. Mean square values for number of siliquae plant^{-1}, siliqua length, number of seeds siliqua^{-1}, 1000-seed weight of rapeseed

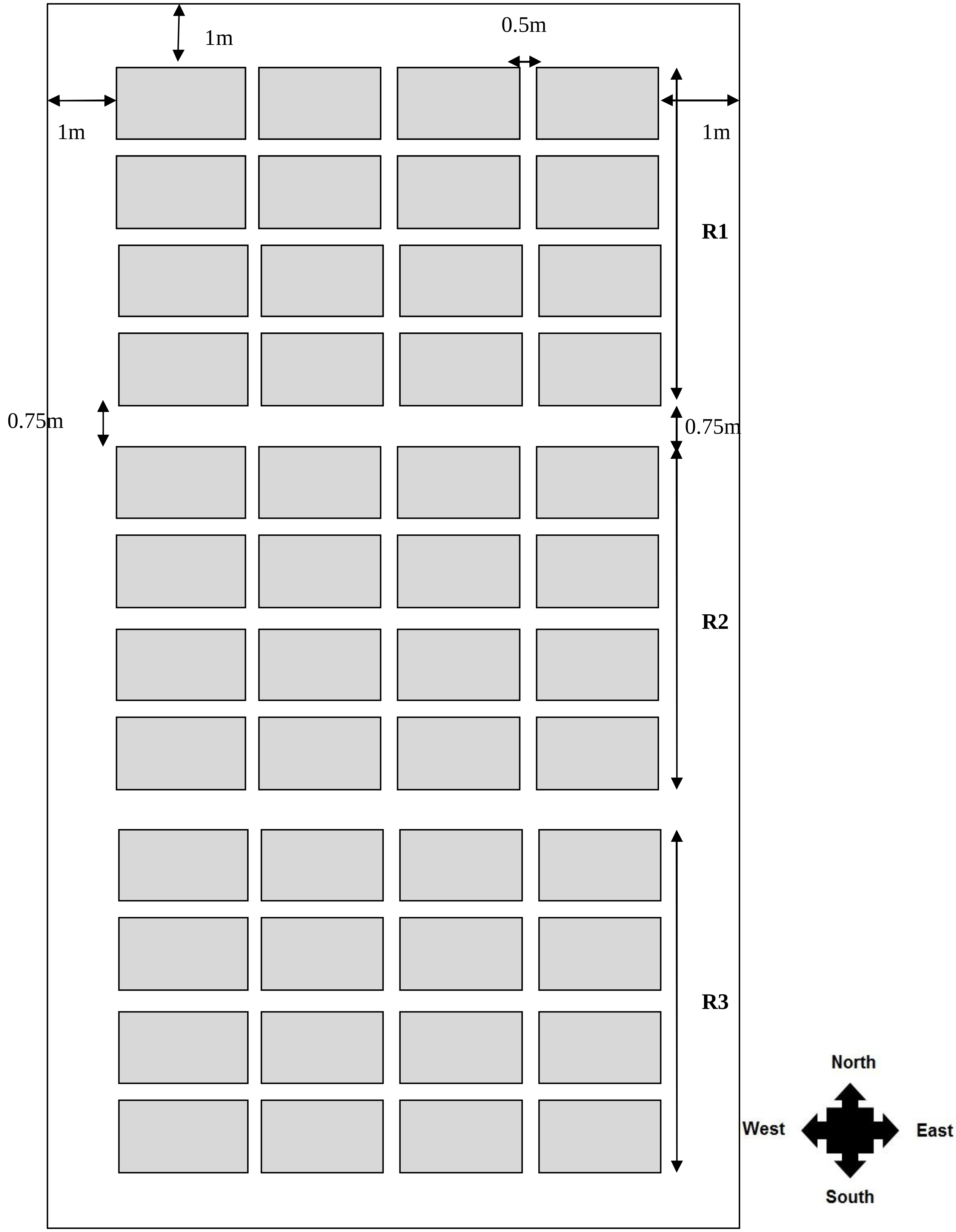
Sources of variation	Degrees of freedom	Mean Square			
		Number of siliquae plant^{-1}	Siliqua length (cm)	Number of seeds siliqua^{-1}	1000-seed weight (g)
Replication	2	23.10	0.01013	11.101	0.03762
Nitrogen	3	4539.02**	0.25712**	151.402**	0.17062*
Error (a)	6	18.92	0.04677	6.220	0.07031
Sulphur	3	138.47**	0.09730**	5.658*	0.09654 **
Nitrogen × Sulphur	9	136.52**	0.07774**	21.619**	0.07165**
Error (b)	24	14.78	0.00534	2.991	0.00642

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

Appendix VI. Mean square values for seed, stover, biological yield and harvest index of rapeseed

Sources of variation	Degrees of freedom	Mean Square			
		Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	0.03245	0.10120	0.2348	4.2681
Nitrogen	3	1.92541**	3.77806**	10.9828**	40.3979**
Error (a)	6	0.02732	0.03752	0.1188	3.2560
Sulphur	3	0.02095 ^{ns}	0.07164 ^{ns}	0.1664**	0.8151 ^{ns}
Nitrogen × Sulphur	9	0.06823**	0.03070*	0.1778**	9.3135*
Error (b)	24	0.02027	0.05246	0.0747	11.7738

**: significant at 0.01 level of probability *: significant at 0.05 level of probability ns: non-significant



Appendix VII. Layout of the experimental field