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Yield and yield components of rapeseed as influenced by nitrogen and sulphur fertilization

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Abstract

Effect of nitrogen (N) and sulphur (S) on yield and yield components of rapeseed (BARI Sarisha-14) was studied at Shere-Bangla Agricultural University Farm, Dhaka, Bangladesh during two consecutive *Rabi* seasons of 2014-15 and 2015-16. The experiment was laid out in split-plot design with three replications, consisted four levels of nitrogen *viz.,* 0 (control), 60, 120, 180 kg ha^{-1}; and four levels of sulphur *i.e.,* 0 (control), 15, 30, 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}.

Key words: *BARI Sarisha-14, brassica campestris, harvest index, macronutrient, seed yield*

Introduction

Rapeseed (*Brassica spp.*) belonging to the family Brassicaceae are important sources of edible oil and currently ranks as the world's third most oil crops after palm and soybean in terms of production and area (Zhang and Zhou, 2006 and Adnan *et al.,* 2013). It has remarkable demand as in Bangladesh for cooking food. Rapeseed tops the list among the oilseed crops grown in this country in respect of both production and acreage (BBS, 2015).

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 apart form biotic stresses. 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 and Rossato *et al.,* 2001), therefore, mineral N fertilization is a crucial factor in oilseed rapeseed production (Dreccer *et al.,* 2000; Rathke and Schuster, 2001 and 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, 2002; Behrens *et al.,* 2002 and 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 and 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 and Qayyum *et al.,* 1998). Excess N, however, can reduce seed yield and quality appreciably (Cheema *et al.,* 2001 and Laaniste *et al.,* 2004).

Sulphur (S) requirement for plant development varies with the developmental stage and with species whereas its concentration in plants varies between 0.1 and 1.5% of dry weight. The deficiency of soil S in the agricultural soils has been reported frequently over the past several years (Scherer, 2001 and 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). 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 and 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.,* 1999). 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 and 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 and 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 to examine the effect of N and S on the yield performances of rapeseed and to investigate the combined effect of N and S on the yield and yield components of rapeseed.

Materials and Methods

Experimental location, soil and climate

The research involved a two-year field experiment (2014-15 and 2015-16), conducted in the agronomy research field, Sher-e-Bangla Agricultural University (23°45' N latitude and 90° 23' E longitude at an elevation of 8.45 m above the sea level), Dhaka, Bangladesh. Both experiments were conducted in the same field and soil samples of the experimental field were analyzed in the laboratory of Soil Resource Development Institute (SRDI) before the experiment set up. Soil pH, total nitrogen, exchangeable potassium, exchangeable calcium, exchangeable phosphorous, exchangeable sulphur, available boron, organic matter were 5.7, 0.072%, 0.33 meq/100 g soil, 6.34 meq/100 g soil, 14.06 mg/g soil, 15.18 mg/g soil, 0.32 mg/g soil, 0.79%. The experimental area is situated in the sub-tropical climatic zone. The average air temperature, relative humidity and rainfall of the two cropping seasons (2014-15 and 2015-16) of the experimental site were also recorded (Table 1).

Table 1: Monthly average air temperature, relative humidity and rainfall of the experimental site during the period from November to February 2014-15 and 2015-16 (mean of two years)

Month	Average air temperature (˚C)		Average relative humidity	Total average rainfall
	Minimum	Maximum	(%)	(mm)
November	20.10	29.70	58.29	5
December	15.84	26.93	68.58	0
January	12.50	24.55	73.39	14
February	24.61	36.86	75.16	34

Source: Sher-e-Bangla Agricultural University mini weather station, Dhaka-1207, Bangladesh

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%.

Experimental design and treatment details

Experimental plots, 10 m^2 (4 m × 2.5 m) in size, were arranged in a split plot design and each treatment was carried out in triplicate. The main plot treatment included 0 kg N ha^{-1} (control), 60, 120 and 180 kg N ha^{-1}. The subplot treatment included different levels of sulphur namely 0 kg S ha^{-1} (control), 15, 30 and 45 kg S ha^{-1}. Interplot spacing of the experiment was 0.50 m and inter block 0.75 m. Plant spacing was maintained with 30 cm and 5 cm, as of line to line and plant to plant distance, respectively.

Land preparation

The land of the experimental field was first opened on October 25, 2014 and 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.

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}).

Seed Sowing

Sowing was done on 6th November, 2014 and 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.

Irrigation

Irrigation was done at three times. The first irrigation was given in the field on 1st December 2014 and 2015 at 25 DAS through irrigation channel. The second irrigation was given at the stage of maximum flowering (35 DAS) on 11th December 2014 and 2015. The final irrigation was given at the stage of seed formation (50 DAS), on 27th December 2014 and 2015.

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.

Biological yield (t ha^{-1})

Biological yield was calculated by using the following formula:

Biological yield= Seed yield + Stover yield

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:

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

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).

Results and Discussion

Plant height (cm)

Different nitrogen levels showed significant effect on plant height of rapeseed at different DAS (Table 2). 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 Table 2 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) and Ahmadi (2010).

The significant result was found in plant height of rapeseed by the sulphur application at different growth stages (Table 2). 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 Table 2 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

Table 2: Effect of different levels of nitrogen and sulphur on plant height of rapeseed at different DAS (mean of two trails)

Nitrogen levels	Plant height (cm) at				
	25 DAS	35 DAS	45 DAS	55 DAS	Harvest
0 kg N ha^{-1}	13.62 c	42.15 d	68.52 c	68.94 c	69.37 c
60 kg N ha^{-1}	15.37 b	45.32 c	77.74 b	79.18 b	80.62 b
120 kg N ha^{-1}	16.83 a	50.17 a	81.96 a	83.32 a	84.69 a
180 kg N ha^{-1}	15.65 b	48.03 b	78.52 b	80.30 b	82.07 ab
$LSD_{(0.05)}$	0.679	1.449	2.829	2.478	3.073
CV (%)	4.42	3.70	4.38	3.77	4.61
Sulphur levels					
0 kg S ha^{-1}	14.93 b	45.26 b	75.21 c	75.79 d	76.16 c
15 kg S ha^{-1}	15.31 ab	46.40 a	75.74 c	76.98 c	78.25 b
30 kg S ha^{-1}	15.46 a	46.92 a	77.07 b	78.90 b	80.53 a
45 kg S ha^{-1}	15.78 a	47.08 a	78.72 a	80.08 a	81.82 a
$LSD_{(0.05)}$	0.495	0.865	1.048	1.118	1.434
Nitrogen × Sulphur levels					
0 kg N ha^{-1} × 0 kg S ha^{-1}	12.87 j	39.27 j	61.35 j	62.89 j	58.99 i
0 kg N ha^{-1} × 15 kg S ha^{-1}	13.14 ij	41.81 i	65.90 i	66.86 i	67.78 h
0 kg N ha^{-1} × 30 kg S ha^{-1}	14.01 hi	43.03 hi	71.26 h	72.93 h	73.85 g
0 kg N ha^{-1} × 45 kg S ha^{-1}	14.48 gh	44.50 gh	74.03 g	74.63 h	76.86 f
60 kg N ha^{-1} × 0 kg S ha^{-1}	14.40 gh	43.15 hi	75.79 fg	77.24 g	78.47 ef
60 kg N ha^{-1} × 15 kg S ha^{-1}	15.23 e-g	45.02 fg	77.03 ef	78.22 fg	79.54 d-f
60 kg N ha^{-1} × 30 kg S ha^{-1}	15.63 d-f	45.39 fg	78.32 de	79.87def	81.20 c-e
60 kg N ha^{-1} × 45 kg S ha^{-1}	16.22 b-d	47.72 de	79.83 b-d	81.39 b-e	83.27 bc
120 kg N ha^{-1} × 0 kg S ha^{-1}	15.59 d-f	46.45 ef	80.37 b-d	81.89 b-d	83.33 bc
120 kg N ha^{-1} × 15 kg S ha^{-1}	16.86 a-c	48.74 cd	80.97 bc	82.42 bc	83.34 bc
120 kg N ha^{-1} × 30 kg S ha^{-1}	17.15 ab	51.78 b	81.50 b	83.34 b	85.02 ab
120 kg N ha^{-1} × 45 kg S ha^{-1}	17.71 a	53.69 a	84.98 a	85.64 a	87.07 a
180 kg N ha^{-1} × 0 kg S ha^{-1}	16.85 a-c	52.18 ab	81.79 b	82.69 b	83.84 bc
180 kg N ha^{-1} × 15 kg S ha^{-1}	15.99 c-e	50.02 c	79.05 c-e	80.41 c-f	82.33 b-d
180 kg N ha^{-1} × 30 kg S ha^{-1}	15.04 e-h	47.51 de	77.22 ef	79.44 e-g	82.06 cd
180 kg N ha^{-1} × 45 kg S ha^{-1}	14.73 f-h	42.41 i	76.04 fg	78.65 fg	80.07 de
$LSD_{(0.05)}$	1.090	1.730	2.095	2.236	2.868
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

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 and Piri *et al.,* 2011a).

Combination of N and S had significant effect on plant height of rapeseed at different DAS (Table 2). 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).

Number of branches plant^{-1}

Different nitrogen levels had significant effect on number of branches plant^{-1} at different growth intervals of rapeseed under study (Table 3). Table 3 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

Table 3: Effect of different levels of nitrogen and sulphur on number of branches plant^{-1} of rapeseed at different DAS (mean of two trails)

Nitrogen levels	Number of branches plant^{-1} at			
	35 DAS	45 DAS	55 DAS	Harvest
0 kg N ha^{-1}	3.35 c	3.59 c	3.82 c	3.83 c
60 kg N ha^{-1}	5.20 b	5.78 b	5.90 b	6.01 b
120 kg N ha^{-1}	6.01 a	6.26 a	6.45 a	6.52 a
180 kg N ha^{-1}	5.54 ab	5.80 b	5.98 b	6.16 b
$LSD_{(0.05)}$	0.491	0.221	0.198	0.452
CV (%)	11.60	4.92	4.24	4.40
Sulphur levels				
0 kg S ha^{-1}	4.64 b	5.12 b	5.28 c	5.28 c
15 kg S ha^{-1}	4.86 b	5.31 ab	5.40 bc	5.48 bc
30 kg S ha^{-1}	5.20 a	5.41 ab	5.61 ab	5.67 b
45 kg S ha^{-1}	5.40 a	5.59 a	5.86 a	6.09 a
$LSD_{(0.05)}$	0.262	0.308	0.302	0.375
Nitrogen × Sulphur levels				
0 kg N ha^{-1} × 0 kg S ha^{-1}	2.67 j	2.87 i	2.93 g	3.00 i
0 kg N ha^{-1} × 15 kg S ha^{-1}	3.00 j	3.30 hi	3.33 g	3.40 hi
0 kg N ha^{-1} × 30 kg S ha^{-1}	3.60 i	3.63 h	4.13 f	3.93 h
0 kg N ha^{-1} × 45 kg S ha^{-1}	4.13 h	4.57 g	4.87 e	5.00 g
60 kg N ha^{-1} × 0 kg S ha^{-1}	4.27 h	5.47 ef	5.57 d	5.47 fg
60 kg N ha^{-1} × 15 kg S ha^{-1}	5.00 fg	5.60 de	5.73 cd	5.73 d-f
60 kg N ha^{-1} × 30 kg S ha^{-1}	5.57 de	5.80 b-e	5.97 b-d	6.27 b-d
60 kg N ha^{-1} × 45 kg S ha^{-1}	5.97 b-d	6.27 a-c	6.32 a-c	6.57 bc
120 kg N ha^{-1} × 0 kg S ha^{-1}	5.50 d-f	5.75 c-e	6.20 a-c	5.93 c-f
120 kg N ha^{-1} × 15 kg S ha^{-1}	5.63 c-e	6.21 a-d	6.36 ab	6.20 b-e
120 kg N ha^{-1} × 30 kg S ha^{-1}	6.30 ab	6.41 ab	6.47 ab	6.67 a-c
120 kg N ha^{-1} × 45 kg S ha^{-1}	6.60 a	6.67 a	6.79 a	7.27 a
180 kg N ha^{-1} × 0 kg S ha^{-1}	6.13 a-c	6.40 ab	6.40 ab	6.73 ab
180 kg N ha^{-1} × 15 kg S ha^{-1}	5.80 b-e	6.13 a-d	6.18 bc	6.57 bc
180 kg N ha^{-1} × 30 kg S ha^{-1}	5.33 e-g	5.80 b-e	5.87 b-d	5.80 d-f
180 kg N ha^{-1} × 45 kg S ha^{-1}	4.90 g	4.87 fg	5.47 de	5.53 e-g
$LSD_{(0.05)}$	0.525	0.617	0.603	0.694
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

concluded from the Table 3 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) reported that number of branches plant^{-1} increased with increasing levels of N up to 120 and 150 kg N ha^{-1}, respectively.

The significant result was found in number of branches plant^{-1} of rapeseed at different sulphur levels (Table 3). Table 3 demonstrated that number of branches plant^{-1} increased with increasing the age of plant irrespective of sulphur levels. It can be inferred from the Table 3 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 Rana *et al.* (2001) and Piri *et al.* (2011a).

Due to the combined effect of nitrogen and sulphur, the number of branches plant^{-1} of rapeseed was significantly affected at different growth stages (Table 3). 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.

Number of siliquae plant^{-1}

Different nitrogen levels had significant effect on number of siliquae plant^{-1} of rapeseed (Table 4). 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).

The number of siliquae plant^{-1} of rapeseed affected significantly by sulphur application (Table 4). The maximum number of siliquae plant^{-1} (63.73) was found from the 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 15 kg S ha^{-1}. Govahi and

Table 4: Effect of different levels of nitrogen and sulphur on number of siliquae plant^{-1}, siliqua length, number of seeds siliqua^{-1} and 1000-seed weight of rapeseed (mean of two trails)

Nitrogen levels	Number of siliquae plant^{-1}	Siliqua length (cm)	Number of seeds siliqua^{-1}	1000-seed weight (g)
0 kg N ha^{-1}	33.73 d	4.42 c	22.26 b	3.12 b
60 kg N ha^{-1}	54.91 c	4.54 bc	28.54 a	3.23 ab
120 kg N ha^{-1}	77.20 a	4.76 a	30.33 a	3.41 a
180 kg N ha^{-1}	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				
0 kg S ha^{-1}	56.16 c	4.49 c	26.86 b	3.14 c
15 kg S ha^{-1}	57.15 bc	4.58 b	27.09 ab	3.23 b
30 kg S ha^{-1}	59.99 b	4.61 b	27.41 ab	3.30 a
45 kg S ha^{-1}	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
Nitrogen × Sulphur levels				
0 kg N ha^{-1} × 0 kg S ha^{-1}	25.80 f	4.16 h	18.60 g	2.93 h
0 kg N ha^{-1} × 15 kg S ha^{-1}	30.33 f	4.36 g	22.20 f	3.12 fg
0 kg N ha^{-1} × 30 kg S ha^{-1}	32.00 f	4.41 fg	23.73 ef	3.20 d-g
0 kg N ha^{-1} × 45 kg S ha^{-1}	46.80 e	4.75 bc	24.50 ef	3.25 c-f
60 kg N ha^{-1} × 0 kg S ha^{-1}	48.13 e	4.40 fg	28.57 cd	3.13 e-g
60 kg N ha^{-1} × 15 kg S ha^{-1}	48.67 e	4.50 ef	28.23 cd	3.22 c-g
60 kg N ha^{-1} × 30 kg S ha^{-1}	59.50 d	4.58 de	28.27 cd	3.24 c-f
60 kg N ha^{-1} × 45 kg S ha^{-1}	63.33 cd	4.68 cd	29.10 cd	3.34 bc
120 kg N ha^{-1} × 0 kg S ha^{-1}	74.27 ab	4.58 de	27.33 de	3.10 g
120 kg N ha^{-1} × 15 kg S ha^{-1}	74.60 ab	4.74 bc	29.63 b-d	3.32 b-d
120 kg N ha^{-1} × 30 kg S ha^{-1}	79.67 a	4.78 bc	30.70 bc	3.58 a
120 kg N ha^{-1} × 45 kg S ha^{-1}	80.27 a	4.92 a	33.73 a	3.65 a
180 kg N ha^{-1} × 0 kg S ha^{-1}	76.43 a	4.80 ab	33.03 ab	3.41 b
180 kg N ha^{-1} × 15 kg S ha^{-1}	75.00 ab	4.71 bc	28.30 cd	3.26 c-e
180 kg N ha^{-1} × 30 kg S ha^{-1}	68.80 bc	4.68 cd	26.93 de	3.18 e-g
180 kg N ha^{-1} × 45 kg S ha^{-1}	64.53 cd	4.48 e-g	26.33 de	3.15 e-g
$LSD_{(0.05)}$	7.074	0.119	3.534	0.131
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

Saffari (2006) and Amanullah *et al.* (2011) 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}.

Combination of nitrogen and sulphur application had significant effect on number of siliquae plant^{-1} of rapeseed (Table 4). The maximum number of siliquae plant^{-1} (80.27) was found from 120 kg N × 45 kg S ha^{-1} which was statistically identical (79.67 and 76.43) with 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 Yasari and Patwardhan (2006) and El-Habbasha and El-Salam (2010).

Siliqua length (cm)

Different nitrogen levels had significant effect on siliqua length of rapeseed (Table 4). 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).

Different rates of sulphur application exerted significant effect on siliqua length of rapeseed (Table 4). 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.

Combination of nitrogen and sulphur application had significant effect on siliqua length of rapeseed (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.

Number of seeds siliqua^{-1}

Different nitrogen levels had significant effect on number of seeds siliqua^{-1} of rapeseed (Table 4). 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}.

Different rates of sulphur application exerted significant effect on number of seeds siliqua^{-1} of rapeseed (Table 4). 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}.

Combination of nitrogen and sulphur application had significant effect on number of seeds siliqua^{-1} of rapeseed (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).

1000-seed weight (g)

Different nitrogen levels showed significant effect on 1000-seed weight of rapeseed (Table 4). 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. Singh (2002) and Ozer (2003) also obtained highest 1000-seed weight with 120 kg N ha^{-1}.

Different rates of sulphur application exerted significant effect on 1000-seed weight of rapeseed (Table 4). 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. Govahi and Saffari (2006) and Amanullah *et al.* (2011) 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}.

Combination of nitrogen and sulphur application had significant effect on 1000-seed weight of rapeseed (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).

Seed yield (t ha^{-1})

Seed is the ultimate output of a crop which determines the efficiency of profitability of crop production enterprise. Different doses of nitrogen fertilizer showed significant variation on the seed yield of rapeseed (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

Table 5: Effect of different levels of nitrogen and sulphur on seed, stover, biological yield and harvest index of rapeseed (mean of two trails)

Nitrogen levels	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
0 kg N ha^{-1}	0.79 c	1.39 c	2.17 d	36.22 c
60 kg N ha^{-1}	1.41 b	2.17 b	3.58 c	39.23 ab
120 kg N ha^{-1}	1.67 a	2.72 a	4.39 a	38.04 b
180 kg N ha^{-1}	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				
0 kg S ha^{-1}	1.33	2.06	3.39 b	38.62
15 kg S ha^{-1}	1.34	2.13	3.47 ab	38.15
30 kg S ha^{-1}	1.38	2.18	3.56 ab	38.51
45 kg S ha^{-1}	1.42	2.24	3.66 a	38.75
$LSD_{(0.05)}$	ns	ns	0.23	ns
Nitrogen × Sulphur levels				
0 kg N ha^{-1} × 0 kg S ha^{-1}	0.69 g	1.30 d	1.99 h	34.79 c
0 kg N ha^{-1} × 15 kg S ha^{-1}	0.71 g	1.31 d	2.02 h	35.29 bc
0 kg N ha^{-1} × 30 kg S ha^{-1}	0.77 fg	1.36 d	2.13 gh	36.33 bc
0 kg N ha^{-1} × 45 kg S ha^{-1}	0.98 f	1.58 d	2.56 g	38.47 a-c
60 kg N ha^{-1} × 0 kg S ha^{-1}	1.33 e	2.11 c	3.44 f	38.55 a-c
60 kg N ha^{-1} × 15 kg S ha^{-1}	1.40 c-e	2.12 c	3.52 ef	39.47 a-c
60 kg N ha^{-1} × 30 kg S ha^{-1}	1.41 c-e	2.22 c	3.63 ef	38.99 a-c
60 kg N ha^{-1} × 45 kg S ha^{-1}	1.48 c-e	2.25 c	3.73 d-f	39.89 a-c
120 kg N ha^{-1} × 0 kg S ha^{-1}	1.49 c-e	2.46 a-c	3.95 c-e	37.62 bc
120 kg N ha^{-1} × 15 kg S ha^{-1}	1.63 a-c	2.74 ab	4.36 a-c	37.31 bc
120 kg N ha^{-1} × 30 kg S ha^{-1}	1.74 ab	2.83 a	4.57 ab	38.13 a-c
120 kg N ha^{-1} × 45 kg S ha^{-1}	1.83 a	2.85 a	4.68 a	39.12 a-c
180 kg N ha^{-1} × 0 kg S ha^{-1}	1.81 ab	2.37 bc	4.18 b-d	43.52 a
180 kg N ha^{-1} × 15 kg S ha^{-1}	1.61 a-d	2.36 bc	3.97 c-e	40.53 a-c
180 kg N ha^{-1} × 30 kg S ha^{-1}	1.58 b-d	2.33 c	3.91 c-e	40.57 ab
180 kg N ha^{-1} × 45 kg S ha^{-1}	1.38 de	2.29 c	3.67 ef	37.54 bc
$LSD_{(0.05)}$	0.238	0.384	0.462	3.092
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 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.

Non-significant variation was observed on the seed yield of rapeseed when the field was fertilized with different doses of S (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). Govahi and Saffari (2006) and Amanullah *et al.* (2011) found that the S fertilization significantly increased the seed yield over control.

Combined application of different doses of nitrogen and sulphur had significant effect on seed yield of rapeseed (Table 5). 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.

Stover yield (t ha^{-1})

Different doses of N fertilizer showed significant variation on the stover yield of rapeseed (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).

Variation in stover yield of rapeseed at different doses of sulphur was non-significant (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) and Piri *et al.* (2011a) also reported an increase in stover yield of mustard with increasing sulphur levels.

Combined application of different doses of nitrogen and sulphur had significant effect on stover yield of rapeseed (Table 5). 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).

Biological yield (t ha^{-1})

The significant result was found in biological yield of rapeseed by the different levels of nitrogen (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).

Variation in biological yield of rapeseed at different doses of sulphur was significant (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).

Biological yield of rapeseed was significantly affected due to the combined effect of different doses of nitrogen and sulphur (Table 5). 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).

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 and Malhi *et al.,* 2007). The significant result was found in harvest index of rapeseed by the different levels of nitrogen (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.

Non-significant variation was observed in harvest index of rapeseed at different doses of sulphur (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.

Combined application of different doses of nitrogen and sulphur had significant effect on harvest index of rapeseed (Table 5). 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.

Conclusion

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.

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